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INVESTIGATIONS OF AN ELECTRICAL GLOW DISCHARGE,  
WHEN INSERTED IN SUPERSONIC AIRFLOW,  
TO DETERMINE ITS DEPENDENCE ON PRESSURE AND VELOCITY

by

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the Degree of  
Master of Science

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Investigation of an electrical circuit diagram.  
The diagram is of a circuit diagram.  
to determine the conditions of operation and voltage.

at 1000 hours in the morning

Department of Agriculture, Washington

Director, of Agriculture  
Washington, D. C.

July 12, 1957

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SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic airflow ( $M = 1.0$  to  $M = 3.0$ ) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from  $M = 1$  to  $M = 3$  effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Platinum wire of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough flow discharge for this experiment ( $M = 1.0$  to  $M = 3.0$ ).
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when initiated in a vacuum of  $10^{-5}$  mm Hg, is sensitive to the following conditions.

1. The glow current is relatively constant regardless of electrode separation.
2. Any sharp corner between lines  $\theta = 1$  to  $30^\circ$  allows the glow current.
3. A greater voltage is required to initiate a glow current for larger electrode spacing, a larger wire size, and a positive wire polarity.
4. Filament wire of 0.003-inch diameter diameter could be used in this investigation because the smaller wire size than it was initiated in a vacuum of  $10^{-5}$  mm Hg.
5. Current flow is to be 50 milliamperes gives enough flow discharge for this experiment ( $\theta = 10^\circ$  to  $\theta = 30^\circ$ ).
6. The shape of the glass and the material from which it is made affect the current flow.
7. The glow changes in size with changes in gas pressure.
8. The glow changes in size with changes in electric field.
9. This device might be used as a static pressure measuring instrument and possibly as a flow velocity indicator.

## INTRODUCTION

Frank David Werner<sup>1)</sup> in his investigation of the possible utilization of an electrical glow discharge as a means for measuring airflow characteristics, found that the glow current from a sharp point is markedly pressure sensitive, somewhat dependent upon velocity, slightly dependent upon humidity, and apparently not dependent upon ordinary temperatures. His investigation was made through a velocity range from zero to 400 feet per second or a Mach number range of from zero to about 0.4.

The primary endeavor in the writer's investigation was to make a preliminary exploration to determine if such a glow would function at all in supersonic airflow, to design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow is pressure or velocity dependent at Mach numbers greater than one. The Mach number range used in this investigation was from 1.0 to 3.0. The facility in which this investigation was carried out was constructed by the writer and Lt. Cdr. F. X. Timmes (graduate student) at the University of Minnesota Aeronautical Laboratories at the Rosemount Research Center, Rosemount, Minnesota.

Since this is the first time an electrical glow discharge from a sharp point has been inserted in supersonic airflow to investigate its dependence on pressures and Mach numbers, it is to be expected that the results obtained will have some experimental errors because of inadequate instrumentation and should be used only as a



INTRODUCTION

When David Brewster in his investigation of the possible utilization of an electrical glow discharge as a means for measuring stellar distances, found that the glow current had a sharp point in intensity versus distance, whereas dependent upon intensity, wavelength, composition upon density, and apparently not dependent upon primary temperature, his investigation was made through a relayed means from 1901 to 1902 for a period of a few months.

The primary interest in the writer's investigation was to make a preliminary examination to determine if such a glow would be obtainable at all in a vacuum tube, in a design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow in vacuum or velocity dependent at such a distance from the point. The glow current was found to be independent of distance and from 1.5 to 2.5. The results in which this investigation was carried out are summarized by the writer and Dr. E. A. Wilson (private communication) in the University of Minnesota astronomical observations at the University of Minnesota, Minneapolis, Minnesota.

When this is the first time an electrical glow discharge from a sharp point has been observed in a vacuum tube, it is to be expected that the results obtained will have some experimental errors because of the extremely low intensity and the fact that only a

guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instrumentation, and to the elimination of some of these errors. However, the general trend of dependence upon Mach number and pressure of the electrical glow discharge from a sharp point will be shown in this investigation.

For this study it was decided to construct a special small size wind tunnel instead of using any of the University's full-scale tunnels. The reason for this decision was the necessity for more flexibility during investigations even though the accuracy of ultimate results may be lowered. Since this was the first use of the sharp point glow discharge in supersonic airflow, many adaptations were more convenient in this setup than in the full-scale tunnel. It is logical that the ultimate check of the data obtained in this tunnel would have to be made in a full-scale tunnel, but that step is beyond the scope of this paper. A single step attempt to use the needle in a full-scale tunnel is shown in the appendix.

The writer is grateful to Professor John D. Akerman for his advice and general direction of the research. Mr. Frank D. Werner was very helpful in the actual design of all the electrical equipment. Professor J. W. Braithwaite was of great assistance in the design and construction of the supersonic wind tunnel.



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 in designing and using equipment to make this investigation  
 should lead to the development of more accurate instrument-  
 ation, and to the elimination of some of these errors.  
 However, the present trend of cooperation with these workers  
 and presence of the electrical give message from a  
 sharp point will be shown in this investigation.  
 For this study it was decided to consider a  
 special case also with some interest of other work in  
 the University's laboratory. The reason for this  
 decision was the necessity for more limited study  
 investigations over the range of values of  
 units may be observed. Since this was the first use of  
 the sharp point and design in previous studies,  
 many experiments were more concerned in this study than  
 in the laboratory. It is hoped that the study  
 which of the data obtained in this study would show to  
 be made in a laboratory, but that was in 1920.  
 The hope of this paper is that it will be of use  
 to the study in a laboratory which is shown in the  
 Appendix.

The writer is grateful to Professor John D.  
 Latham for his advice and general direction of the  
 research. Mr. John D. Latham was very helpful in the  
 design of all the electrical equipment. (Appendix)  
 A. H. Latham was of great assistance in the design  
 and construction of the apparatus and instrument.



## METHODS

The Laval nozzle was made of lucite for two reasons: First, because of its transparency, through lucite it is possible to observe the electrical glow discharge at different Mach numbers and at different static pressures. Second, since lucite is a good insulator, there was no danger of a current flow to ground through the nozzle if a short occurred. Lucite has proved to be an excellent material to satisfy the above requirements.

The probes were designed to be strong enough so that they would not bend in supersonic airflow. Also, a coating of arcylold, which is a liquid plastic that hardens in about 48 hours, was used on each probe not only to give more rigidity but also to act as an insulator. The insulatory properties of the coating were essential, especially where the probes were close together, to avoid arcing downstream of the platinum wire. Care was taken not to coat the plate circuit nor the platinum wire with the liquid plastic. Arcylold proved to be an excellent insulator.

When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

The first series was made of single test  
reactions. First, because of its frequency, through  
which it is possible to observe the electrical wave  
change at different load numbers and at different static  
pressures. Second, since there is a good knowledge  
there was no change of a constant flow in current through  
the series in a short circuit. Since the first is in  
an electrical circuit it is really the same phenomenon.  
The series were designed to be strong enough  
so that they would not break in subsequent series. Also,  
a coating of graphite, which is a little plastic in  
nature in water in water, was used on each test set  
only to give more rigidity and also to put on an insulator.  
The insulating properties of the series were essential,  
especially where the series were also tested. It  
was also tested in the series. One was  
taken out to test the series and the series was  
with the series. The series proved to be an  
excellent insulator.  
When the series circuit was tested and the  
also tested, necessarily current readings were recorded.  
When the series was tested and the series was tested, current  
readings were as small as the electrical equipment  
allowed for those tests and not about any current flow.  
These readings were current readings were recorded when the  
also was negative. This type of circuit was used in series



the electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Werner<sup>1</sup>).

The writer has found in this investigation that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an arcing stage; therefore, erratic current readings resulted at this high voltage. For this reason, lower current readings were used in the magnitude of from 60 to 80 microamperes. Enough points were recorded at these lower currents to plot smooth curves as are shown in Figures 2 through 6. From this it can be concluded that the use of lower current will give more stable readings and will give more accurately the trend of events under investigation.

The electronic equipment was designed to give from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two circuits could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use more than 10,000 volts; therefore, it was not necessary to connect the two circuits together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate circuit which also acted as the static probe while the ground (shield



The electrical and discharge system consists of the theory behind this phenomenon is explained schematically in the paper entitled "The Discharge System".

The water has been in this investigation

that various readings were obtained up to 500 micrometers at high voltage readings. At these high voltages and currents the electrical field discharge was almost at an active stage; therefore, active current readings were obtained at this high voltage. For this reason, lower current readings were used in the magnitude of from 50 to 100 micrometers. These points were recorded at these lower currents to give a more complete picture of the system in figure 2 through 4. From this it can be concluded that the use of lower current will give more stable readings and all five were recorded; the trend of events under investigation.

The electronic equipment was connected to five from zero to 10,000 volt positive and from zero to 10,000 volt negative. These two electrodes could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use zero and 10,000 volt; therefore, it was not necessary to connect the two electrodes together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate directly while the negative lead was connected to the ground (which

of co-ax cable) of the circuit was connected to the probe holding the 0.003-inch platinum wire.

at which time the circuit was completed in the

series between the 0.005-inch distance after

it was found that a single layer of

material was not sufficient

and it was found that a double layer of

material was necessary to obtain the

desired results. The thickness of the

material was found to be approximately

0.005 inches and the distance between the

layers was found to be approximately

0.005 inches. The material was found to be

approximately 0.005 inches thick and the

distance between the layers was found to be

approximately 0.005 inches. The material

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## EQUIPMENT

Figure 31 shows the wind tunnel nozzle, the manometer board, the electrical equipment, and the probes. Figure 25 is a drawing, to scale, of the wind tunnel. Figure 26 is a scale drawing of the Laval nozzle blocks. Figures 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 225-pound-per-square-inch storage tank of 1750 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure steel pipe. A 1-inch gate valve was used to control the air leaving the high pressure storage tank. The air enters the stagnation chamber of the wind tunnel through a 2-inch pipe. A 2-inch globe valve was installed in the 2-inch pipe line for use as a throttling valve. Stagnation pressures in the stagnation chamber were maintained by adjusting the 2-inch throttling valve.

A total head pressure gage was designed as shown in Figure 25. It consisted of a 1/4-inch steel pipe which held a hypodermic needle. This pipe was placed in the stagnation chamber as shown in the scale drawing of the wind tunnel (Figure 25). One end of this steel tube was plugged while the other end was connected to a pressure gage with a scale from zero to 100 pounds per square inch. It was found that this gage gave pressure readings accurate to within one percent of their correct value.

Figure 2) shows the wind tunnel model, the transmitter board, the electrical equipment, and the pressure. Figure 3 is a drawing, in cross, of the wind tunnel. Figure 4 is a scale drawing of the wind tunnel. Figures 5, 6, and 7 are drawings of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 200-pound-per-square-inch storage tank of 150 cubic feet capacity. The high pressure air leaves the tank through a 1-inch high pressure pipe. A 1-inch pipe valve was used to control the air leaving the high pressure storage tank. The air enters the expansion chamber of the wind tunnel through a 2-inch pipe. A 2-inch pipe valve was installed in the 2-inch pipe/line for use as a throttling valve. Expansion pressure in the expansion chamber was obtained by adjusting the 2-inch throttling valve.

A total wind pressure gauge was installed as shown in Figure 8. It consisted of a 1 1/2-inch steel pipe which held a hypodermic needle. This pipe was placed in the expansion chamber as shown in the scale drawing of the wind tunnel (Figure 9). One end of this pipe was plugged while the other end was connected to a pressure gauge with a scale from zero to 100 pounds per square inch. It was found that this gauge gave accurate readings because it reads the pressure of the air in the



A standard type mercury manometer was constructed and used throughout this investigation to measure static pressure. Figure 31 shows this manometer as it was used to measure static pressures.

Figure 25 shows the bell-mouth entrance to the nozzle. This bell-mouth, made of hydrostone, proved to be very satisfactory. No cracking or chipping of the bell-mouth was noticed at the completion of this investigation.

Figure 26 is a scale drawing of the Laval nozzle blocks. The blocks and side plates were made of lucite and were designed to give a Mach number from 1.0 to 3.0, but a manufacturing error was made which gave a slightly different Mach number. This difference is shown in Figure 1. It can also be seen in Figure 1 that the experimental Mach numbers are slightly less than the theoretical Mach numbers at the same positions in the nozzle, but still gave satisfactory Mach numbers for  $M = 1.0$  to  $M = 3.1$ .

The probes, as shown in Figures 30 and 33, were made of 1/4-inch steel tubing. The static probe also acted as the plate of the circuit. A 1/16-inch brass tube was inserted in the upstream end of the static probe. A static hole was drilled in this brass tube 8 diameters from the upstream end. The upstream end of the 1/16-inch brass tube was closed by silver solder and ground to a very fine point. A 1/16-inch solid steel rod was inserted in the upstream end of the glow probe that held the



A standard type mercury manometer was connected to the end of the tube. This investigation is made at a pressure of 10 mm. Hg. The tube is connected to the end of the mercury manometer.

Figure 1 shows the self-acting manometer for the normal. This bell-mouth, made of pyrex, is connected to the end of the tube. It consists of a glass of the bell-mouth and a portion of the manometer of this investigation.

Figure 2 is a sketch showing of the tube and the bell-mouth. The tube and the bell-mouth are made of glass and were designed to give a water column from 1.0 to 2.0. A manometer tube was used which gave a reading of 1.0 mm. Hg. This difference is shown in Figure 2. It can also be seen in Figure 1 that the experimental data are very similar to those from the theoretical data. The difference in the manometer, but will have satisfactory results. The difference is 1.0 to 2.0.

The problem, as shown in Figure 2, and 2.0, was made at 1/4-inch steel tubing. The tube is also connected to the plate of the manometer. A 1/4-inch glass tube was inserted in the specimen and at the same time. A steel tube was drilled in this tube from 0.1 inches to the specimen end. The specimen was of the 1/4-inch steel tube was placed in a glass tube and fixed in a very fine point. A 1/4-inch steel tube was inserted in the specimen and at the same time. The tube

platinum wire. This upstream end of the solid steel rod was also ground to a very fine point. The 0.003-inch platinum wire was soldered to the upstream sharp end of the steel rod.

Both probes were coated with arcyloid which is a liquid plastic that hardens in about 48 hours. These probes were mounted in lucite holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the nozzle. Figure 32 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 28. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 29. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltmeter and ammeter circuits (Direct Current) were designed as shown and were used to measure currents in microamperes and voltages. All voltmeter and ammeter readings are accurate to within 5 percent of their actual value. Both circuits were installed in the same panel as shown in Figure 31.

platinum wire. This specimen was of the same size and was also ground to a very fine point. The 0.002-inch platinum wire was adjusted to the specimen about one of the steel rods.

Both probes were coated with a special oil which is a liquid plastic that remains in place on the probe. The probes were mounted in the holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the specimen. Figure 22 shows the probe support and the track on which it could be moved.

The electric circuit was designed in two separate parts. The circuit for the probe was shown in Figure 23. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for the probe was shown in Figure 24. This circuit produced a positive voltage of from zero to 10,000 volts. The circuit for the probe and the circuit for the probe support were designed as shown and were used in various manners in the laboratory. All voltages and transfer readings are accurate to within 1 percent of their actual values. Both circuits were included in the same panel as shown in Figure 25.



TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrical glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.08 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 94, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures are to be expected and check very

THE RESULTS

The static force, which also acted as the force of the electrical field, was inserted in the nozzle at 0.75-inch from the nozzle with the static force just opposite the 0.75-inch position. At this position in the nozzle were made the different measurements. The electrical pressure was changed through a range of values to determine the electrical pressure that produced the approximate theoretical maximum velocity in the nozzle at the 0.75-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure was followed above and below. A series of the results is shown in figure 1.

It was found that satisfactory velocities of 20, 30, and 40 pounds per square inch were made with a static force of 2.00 at the 1-inch position. Satisfactory velocities of 20, 30, and 40 pounds per square inch were made with a static force of 2.44 at the 2-inch position. The 3 and 4-inch positions were studied in the same manner, and satisfactory velocities of 2.8 and 3.1 were obtained. Satisfactory velocities of 20, 30, and 40 pounds per square inch were made at the 5-inch position, and 30, 35, and 40 pounds per square inch were used at the 6-inch position. It was found that values certain satisfactory pressures for each velocity at any position could not be obtained. Since the nozzle did not have a diameter attached to its exit, these high static pressures did not go to the nozzle and about 200



closely to those given in reference 5.

After the static probe Mach number calibration (Figure 1) was made at the various positions in the nozzle, the probe that held the small platinum wire was placed in position. The 0.003-inch platinum wire on this probe was lined up just opposite the static hole in the static probe. With the wire and plate at 0.25-inch spacing between them inserted in the nozzle at the various positions, runs were made as described in the preceding paragraph. Using this configuration, it was found that the same static pressures as obtained with the static probe alone were obtained at any position using corresponding stagnation pressures, thus showing no effect of the glow probe on static pressure and Mach number at locations under investigation.

With the probe spacing of 0.25-inch and the stagnation pressures necessary to produce the Mach number at any given position, runs were made at the various positions in the tunnel. The same procedure was followed for a 0.125-inch spacing. Ammeter and voltmeter readings were recorded during each run.

Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-400 F.) was used throughout the investigation.

A vacuum jar was used to determine pressure effect on the glow discharge at zero Mach number. The



closely to those given in column 2.

After the static probe was made, the following

(Figure 1) was made at the various positions in the

static, the probe was held in the same position and

placed in position. The 0.005-inch distance was on the

probe was lined up just opposite the static probe in the

static probe. With the wire and plate at 0.005-inch

spacing between them located in the static at the various

positions, some were as described in the preceding

paragraph. Using this method, it was found that

the same static pressure is obtained with the static

probe when some obtained at any position with the static

the static pressure, some were as shown in the

five probe on static pressure was made at various

static investigation.

With the probe spacing of 0.005-inch and the

static pressure pressure was made at various

at any given position, some were as shown in the

positions in the static. The same pressure was obtained

for a 0.005-inch spacing. Another and different results

were recorded using zero gap.

Since some were made as previously described, it

was assumed that for any one the static pressure

constant. Also, the air (0.005 inch) was used throughout

the investigation.

A system of air was used to determine pressure

effect on the static pressure at zero gap. The

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often ventilated to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

plays and also used in the various (as also made of the  
 more material and were the same size. Various designs  
 were also used in the (as also made of the  
 various designs were also used. The (as also made of the  
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 2 (as also made of the



TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the barometer reading are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave.

Figures 1 through 7 give microamperes versus volts at various Mach numbers ranging from zero to 3.1. The space between the plate and the wire was 0.25-inch. These curves show that the glow discharge is definitely dependent on pressure.

Figures 8 through 12 give absolute pressures versus volts at various current flows. The data for these curves were obtained from the microamperes versus volts curves (Figures 1-7).

The final curve, Figure 13, shows the effect of Mach number. Here microamperes versus volts at constant absolute pressure were plotted. After studying these curves, it can be readily seen that the glow discharge is velocity dependent. It can be seen that all curves from  $M = \text{zero}$  to  $M = 2.8$  have the same general trend, but the  $M = 3.1$  curve is different. This is probably due to experimental errors and to poor supersonic airflow at the 4-inch position. Nevertheless, all the





curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge.

The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not plot in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some airflow interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number.

Figure 34 shows a spark photograph of the nozzle blocks at a Mach number of zero. It can be seen that the channel walls are fogged up; this is due to poor glueing of the side plates to the nozzle blocks, indicating that the glue had run down the walls of the nozzle. The black heavy line below the channel is a tape measuring device for placing probes at exact position in the nozzle.

Figure 35 shows the same nozzle with supersonic airflow at a Mach number of 2.81. Shock waves at the 4-inch position can be seen. Also, at about the 4-inch position the flow starts to separate, and by the time it



either end of the same period of time and distance.

The same number has no effect on the electrical flow

discharge.

The two large wires, which are 1/2 inch in

diameter, are under the same conditions as above except

that the spacing of the plates and wire was reduced to

0.125-inch. Again it can be seen that the electrical

flow discharge is practically and nearly constant.

However, this time the two wires were 0.125 inch

in the same position. This is partly due to experimental

error, and it is expected that at the 0.125-inch spacing

there is some slight interference between the plates and

the wire, even though it is not one of the wires

used. These factors, even though they are of little

importance, show a general trend which indicates that

the flow discharge is dependent on these factors.

Figure 10 shows a series of photographs of the plates

driven at a fixed number of turns. It can be seen that the

discharge is not constant; this is due to the fact that

of the plates at the same distance, indicating that

the flow is not constant with the distance. The plates

have five pairs of wires, and a large number of wires

for spacing plates at various positions in the series.

Figure 11 shows the same plates with a different

spacing of a fixed number of turns. Again it can be seen

that the flow is not constant with the distance. The plates

have five pairs of wires, and a large number of wires

reaches the end of the nozzle it appears to have separated almost completely. Due to the cloudy sides of the channel nothing else can be seen.

Figure 36 shows the same nozzle block with supersonic airflow at a Mach number of 2.81, but this time the probes are inserted in the nozzle. The spacing between the plate and wire was 0.25-inch. Here it appears that the probes have helped the flow, but again due to reflection through the top wall of the channel and cloudy channel walls, little of importance can be seen. Even though the flow appears better with the probes inserted, the static probe manometer readings indicated that <sup>at</sup> the 4-inch position separation and turbulent flow exists.

Since this experimentation was the first exploration of the supersonic flow by means of sharp point glow discharge, the establishment of methods, trends, limitations, and possible expectations for this type of flow study was more important than finality of results. At the start of the investigation it was not possible to predict in which direction to concentrate and, therefore, a flexibility in general of instrumentation was more important than fine accuracy of any one item in particular, but even with this procedure, the accuracy of all test data is limited only by the type of instrumentation used and the accuracy with which it was read. Considering the type of gages and electronic equipment used, an overall

position the end of the vessel is shown as being supported almost completely. Use for the study of the vessel's holding area can be seen.

Figure 50 shows the same vessel from a different

position, showing a small number of 2.0, but this

time the vessel was located in the vessel. The vessel

appears the vessel was with one 2.0-inch. Part of

appears that the vessel was being held in place, but again

due to reflection through the top wall of the vessel and

during normal sailing, little or no vibration can be seen.

Even though the line appears rather close to the vessel

position, the study of the vessel's position is not

the same as the vessel's position and position of

exists.

Figure 51 shows the vessel's position and the first ex-

position of the vessel's position by means of a small

line diagram. The vessel's position is shown, showing

limitations, and position of the vessel's position

the study of the vessel's position is shown, showing

At the end of the vessel's position is shown, showing

position in which position is shown, showing

a diagram in which position is shown, showing

position in which position is shown, showing

but even with this position, the vessel's position is not

and is limited only to the study of the vessel's position

and the study of the vessel's position is shown, showing

type of vessel and position of the vessel's position



accuracy of all test data is approximately 95 percent.

Account of all last year is approximately as follows.

The first part of the year was very dry and hot.

The second part of the year was very wet and cold.

The third part of the year was very dry and hot.

The fourth part of the year was very wet and cold.

The fifth part of the year was very dry and hot.

The sixth part of the year was very wet and cold.

The seventh part of the year was very dry and hot.

The eighth part of the year was very wet and cold.

The ninth part of the year was very dry and hot.

The tenth part of the year was very wet and cold.

The eleventh part of the year was very dry and hot.

The twelfth part of the year was very wet and cold.

The thirteenth part of the year was very dry and hot.

The fourteenth part of the year was very wet and cold.

The fifteenth part of the year was very dry and hot.

The sixteenth part of the year was very wet and cold.

The seventeenth part of the year was very dry and hot.

The eighteenth part of the year was very wet and cold.

The nineteenth part of the year was very dry and hot.

The twentieth part of the year was very wet and cold.

The twenty-first part of the year was very dry and hot.

The twenty-second part of the year was very wet and cold.

The twenty-third part of the year was very dry and hot.

## CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between  $M = 1$  and  $M = 3$  change effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Platinum wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment.
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

The following recommendations are given below:

1. If lucite nozzle blocks are to be made for this tunnel, it is recommended that great care be taken in the glueing process to give clear and smooth walls.
2. Nozzle blocks should be made by the method of characteristics, thus eliminating the bad flow conditions encountered in the Laval nozzle.



LOCATIONS AND RECOMMENDATIONS

It is recommended that an additional flow rate

be added when located in appropriate areas and

following recommendations:

1. The flow pattern is relatively pressure sensitive.
2. The flow pattern is dependent on velocity -  
that is, any small change in velocity  $N = 1$  and  $N = 2$   
change affects the flow pattern.
3. A higher velocity is required to maintain a flow  
constant for larger pressure drops, a larger  
flow rate, and positive flow pattern.
4. Flow rate with 0.005-inch diameter must be used  
in this installation because any smaller size  
flow rate would be affected in significant  
manner.
5. Current flow rate is 10 micrometers flow  
through flow channels for this installation.
6. The shape of the flow and the velocity flow  
which is most affected the current flow.
7. The flow pattern in this area changed in time  
manner.
8. The flow changed in this area change in time  
manner.
9. This device should be used as a static  
pressure measuring instrument and possibly as a  
flow control device.

The following recommendations are given below:

1. If lower flow rate is to be used for this  
device, it is recommended that flow rate be  
taken in the flowing device to give flow rate  
control.
2. Device should be used as a static  
pressure measuring instrument and possibly as a  
flow control device in the flow rate.

3. An extremely sensitive type of throttling valve be incorporated in the equipment to enable the operator to hold stagnation pressures more closely to the desired value.
4. An accurate means of measuring stagnation pressures be used. It is suggested that an electronic gage (strain gage) be used.
5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.
6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.
7. A high voltage fuse should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.
8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.
9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and if it is not too expensive to manufacture, should be tried in the next experiments.

3. An electrically sensitive type of photoelectric cell  
be incorporated in the equipment to enable the  
operator to hold magnetic pressure more closely  
in the desired range.
4. An electric means of measuring magnetic pressure  
have no need. It is suggested that an electric  
type (strain gauge) be used.
5. A second holder for the probe should be designed  
so that it will give good accessibility to a  
range in spacing of probe and wire.
6. The two probes should be made of a strong in-  
sulating material, thus eliminating steel loading  
and rigid plastic insulations.
7. A high voltage time should be used in the  
electric equipment to avoid any voltage loss  
the wire is broken by the probe supply.
8. A vibrator and an amplifier circuit should be  
designed to measure the voltage and the current  
from the two power supplies are connected in  
series.
9. A separate switch for five power points and enough  
strength as withstood wire used as an assembly  
and it is not too expensive to manufacture.  
should be tried in the next experiments.



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6. LEE, W. D. "Investigation of the effects of the addition of an inhibitor to the reaction between the reacting ethyl chloroacetate." *Chemical Abstracts*, 1949, 43, 10000.
7. LEE, W. D. "Investigation of the effects of the addition of an inhibitor to the reaction between the reacting ethyl chloroacetate." *Chemical Abstracts*, 1949, 43, 10000.



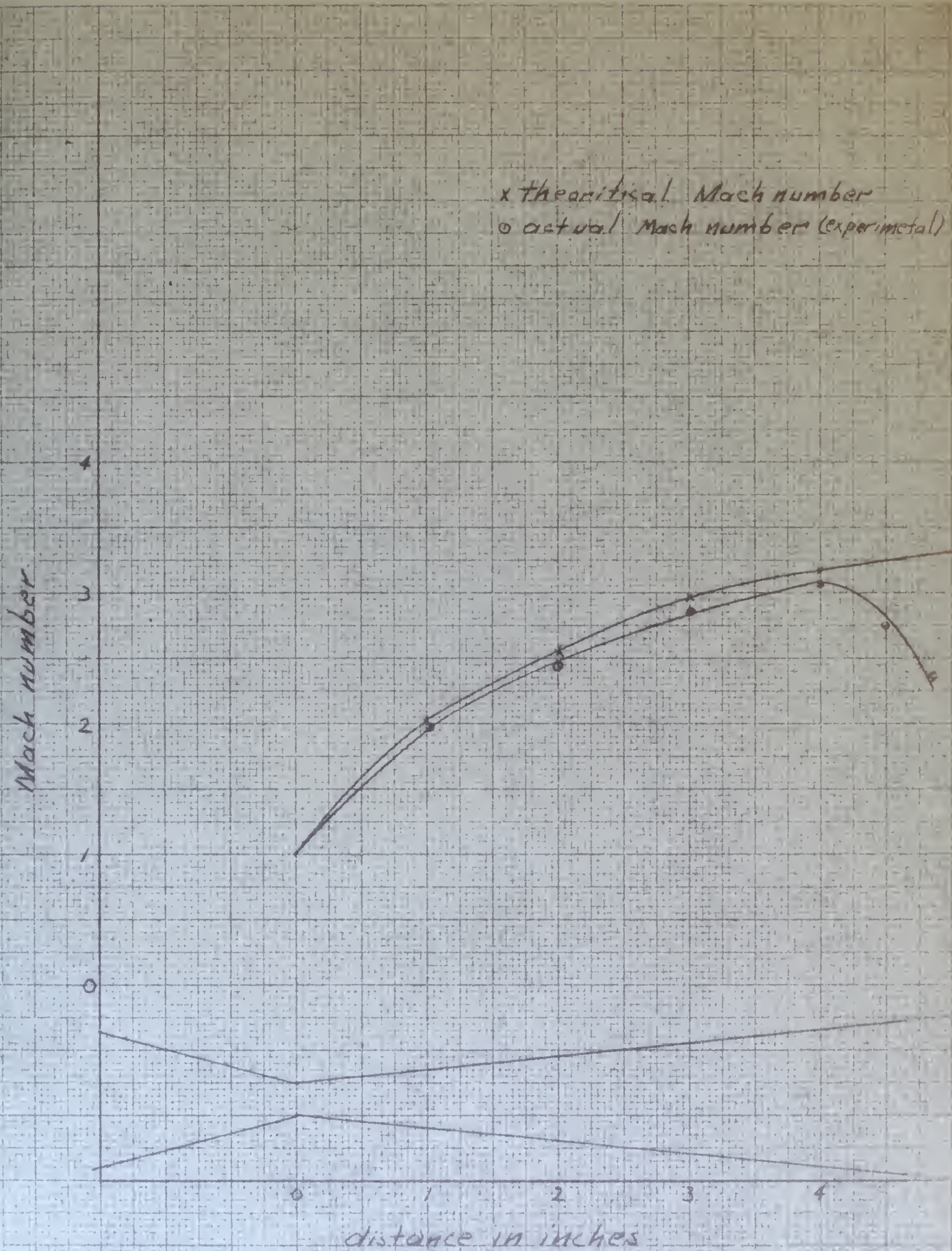


Fig-1-





Voltage VS Current for absolute Pressures  
between 29.14 inches Hg and 4.12 inches Hg.

Mach number equal 0

Wire .003 platinum spacing .25 inches

Dry air

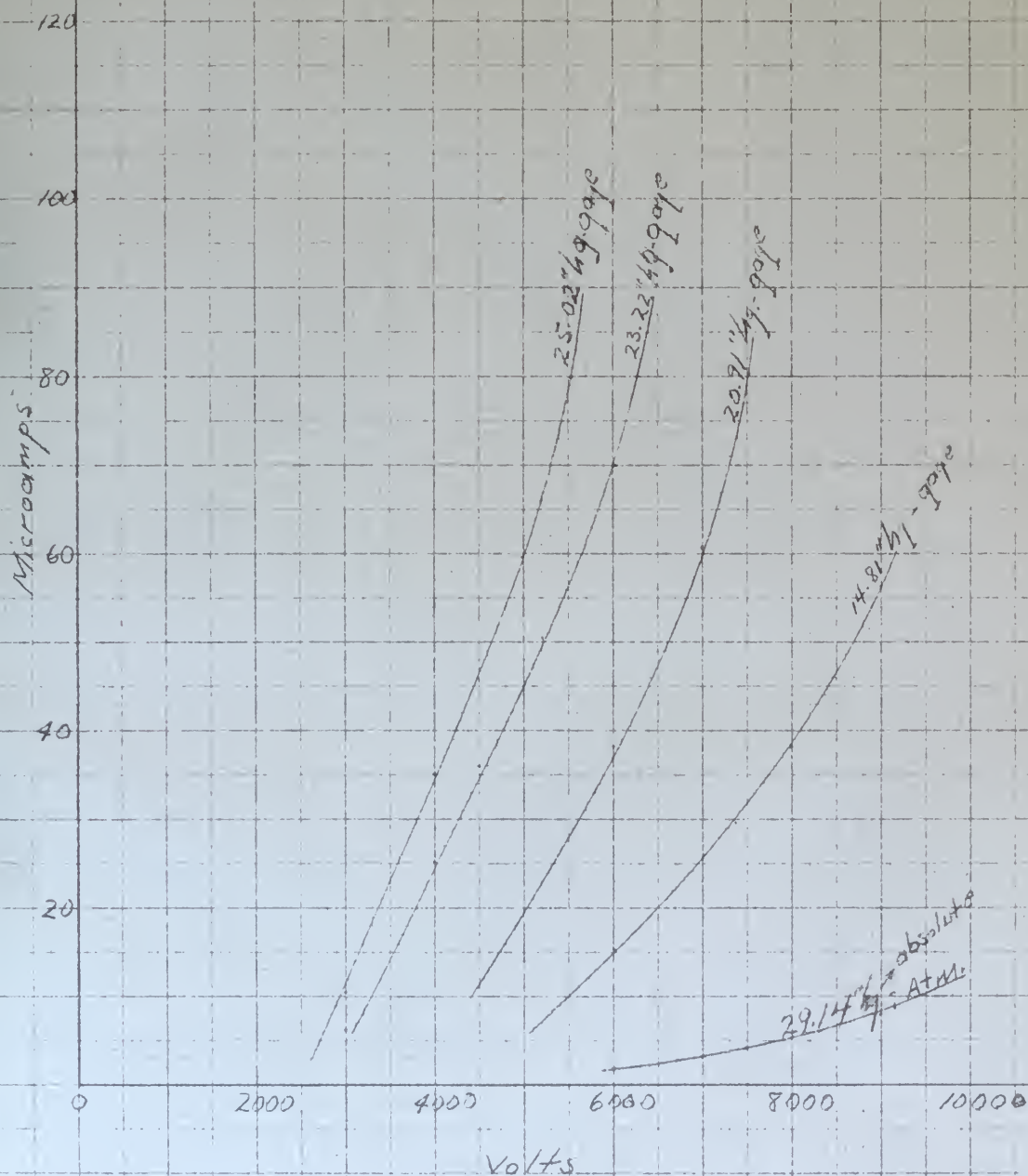


Fig. 2 -





# Microamps Vs Volts

Wire - .003 spacing .25 inches

Position .71 inches in nozzle

Mach number 1.72

140 Stagnation pressure 21.0  $\frac{\text{lb}}{\text{in}^2}$  abs; static probe 5.4  $\frac{\text{lb}}{\text{in}^2}$  abs  
 " " 21.8  $\frac{\text{lb}}{\text{in}^2}$  abs; " 4.3  $\frac{\text{lb}}{\text{in}^2}$  abs  
 " " 27.8  $\frac{\text{lb}}{\text{in}^2}$  abs; " 4.2  $\frac{\text{lb}}{\text{in}^2}$  abs

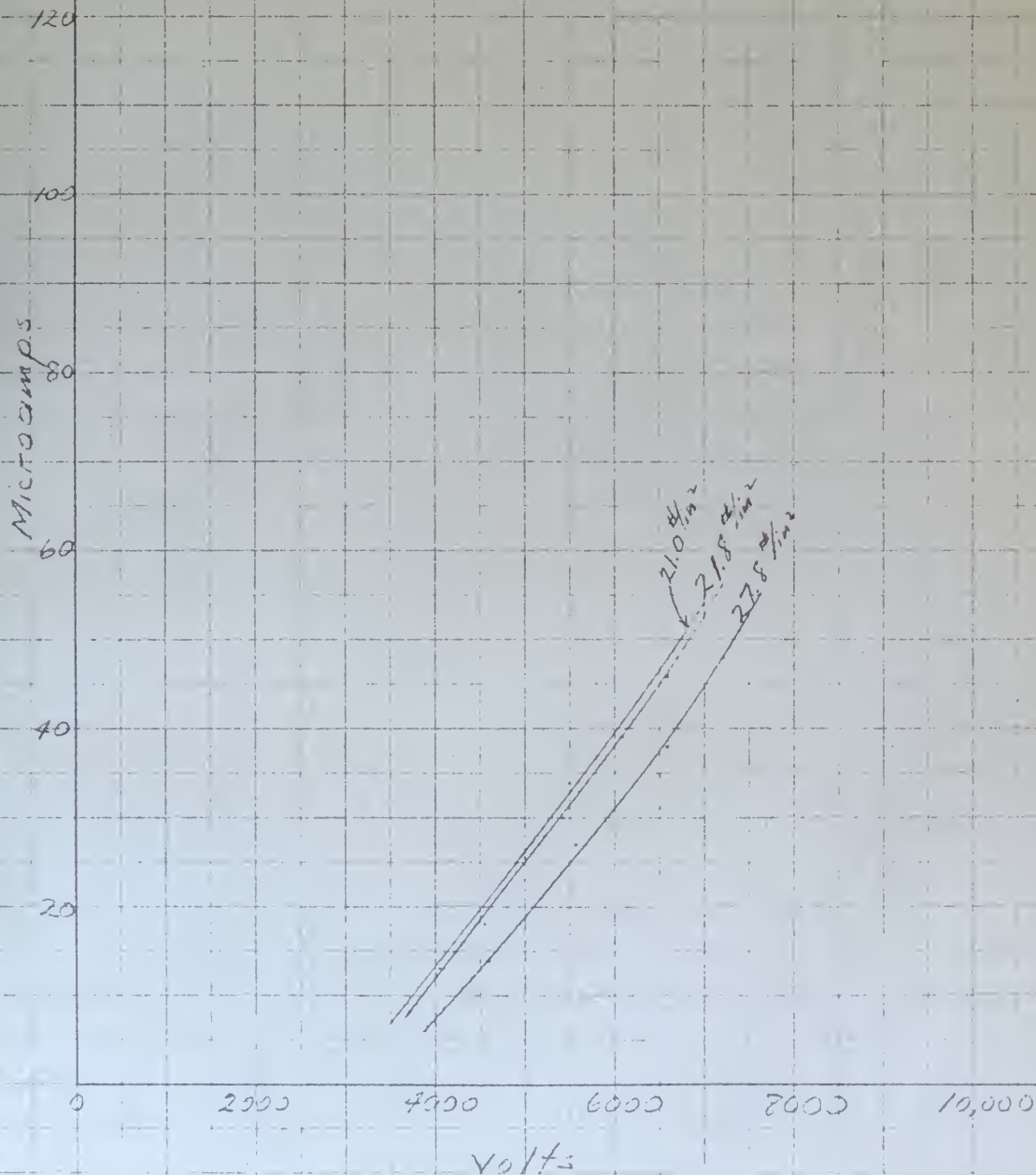


Fig-3-



# Microamps vs Volts

.003 wire

.25" spacing

1" position in nozzle

Mach number = 2.08

Stagnation pressure at 25# gage; static probe 10.3 #/sq in  
 " " " 30# gage; " " " 9.15 #/sq in  
 " " " 40# gage; " " " 7.15 #/sq in

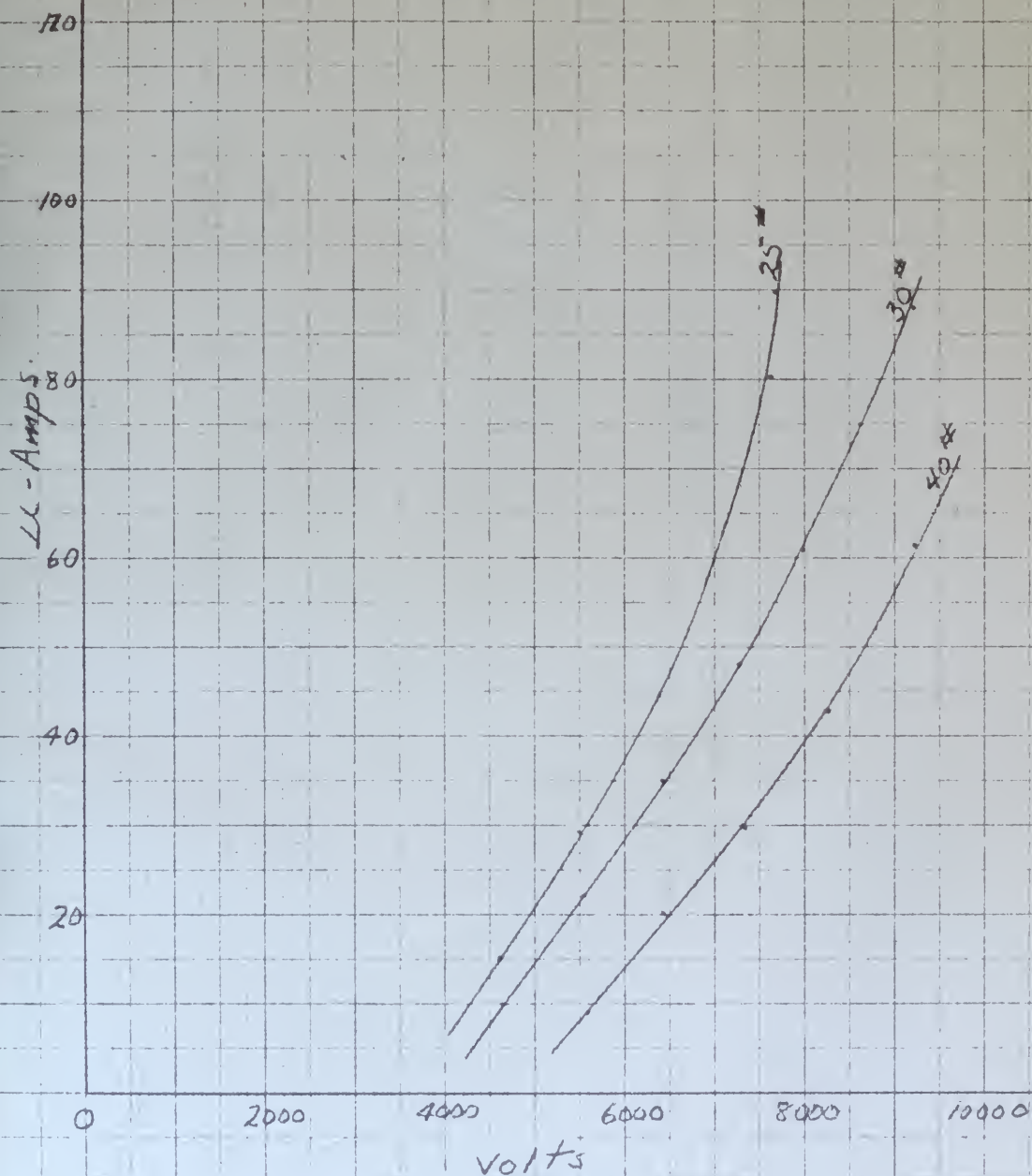


Fig-4-





## Microamps Vs Volts

Wire - .003 platinum

Spacing - .25 inches

Position in nozzle 2"

Mach number = 2.49

Stagnation pressure of 40# gage; static probe 11.5# gage

50# gage; " " 10.2# gage

60# gage; " " 9.2# gage

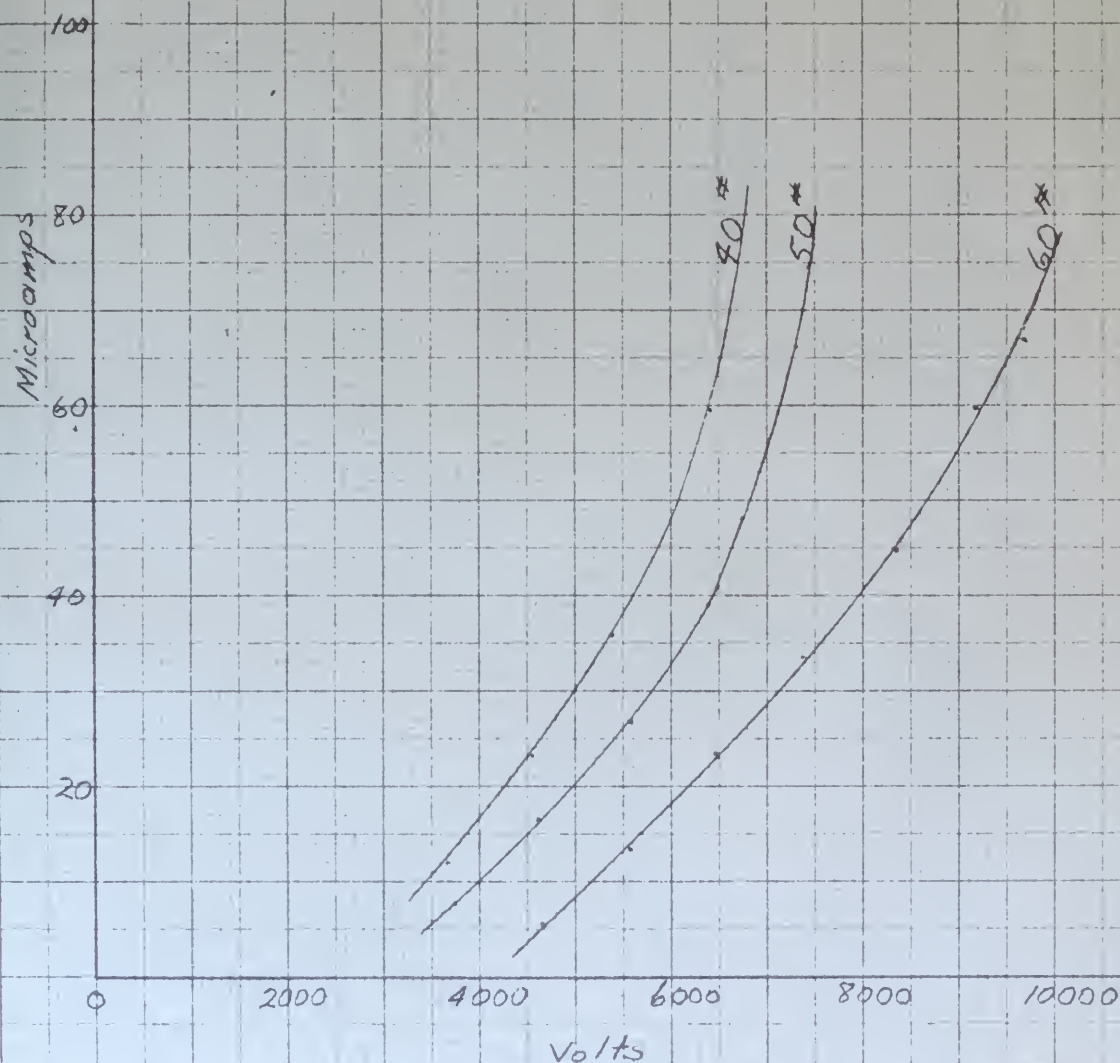


Fig-5-





# Microamps vs Volts

Wire - .003 platinum

Spacing .25 inches

Position 3 inches from throat

Mach number 2.81

Stagnation pressures of 70<sup>th</sup> gage; static probe 16.7 #/sq in.

Stagnation pressure of 80<sup>th</sup> " " " " 16.0 #/sq in.

Stagnation pressure of 90<sup>th</sup> " " " " 15.2 #/sq in.

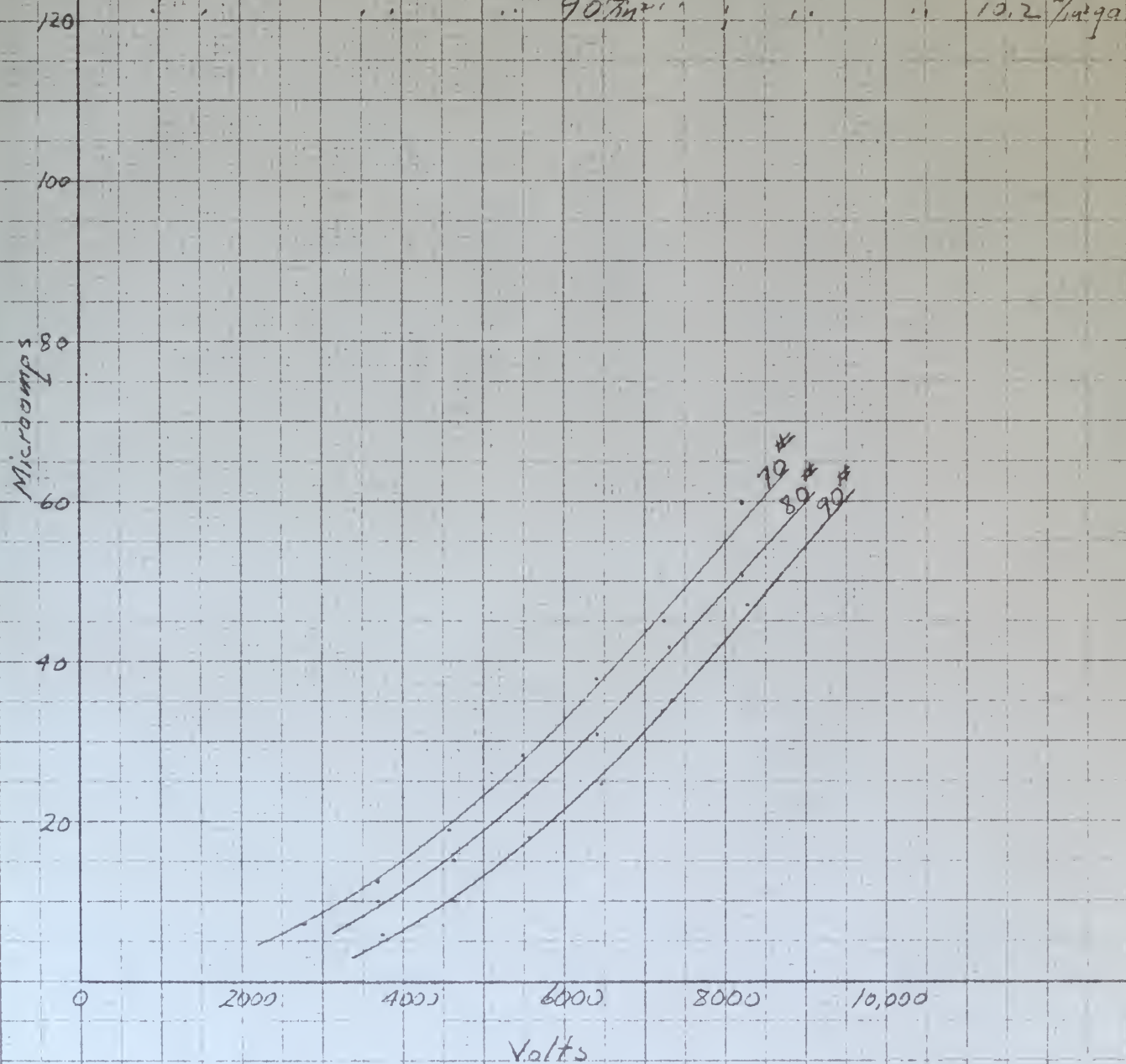


Fig-6-



# Microamps vs. Volts

Wire .003 platinum

Spacing .25 inches

Position in nozzle 4"

Mach number = 3.1

Stagnation pressure 90  $\frac{\text{lb}}{\text{in}^2}$  gage ; static probe 12.4  $\frac{\text{lb}}{\text{in}^2}$  gage  
" " 94  $\frac{\text{lb}}{\text{in}^2}$  " ; " " 12.1  $\frac{\text{lb}}{\text{in}^2}$  "  
" " 100  $\frac{\text{lb}}{\text{in}^2}$  " ; " " 11.87  $\frac{\text{lb}}{\text{in}^2}$  "

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

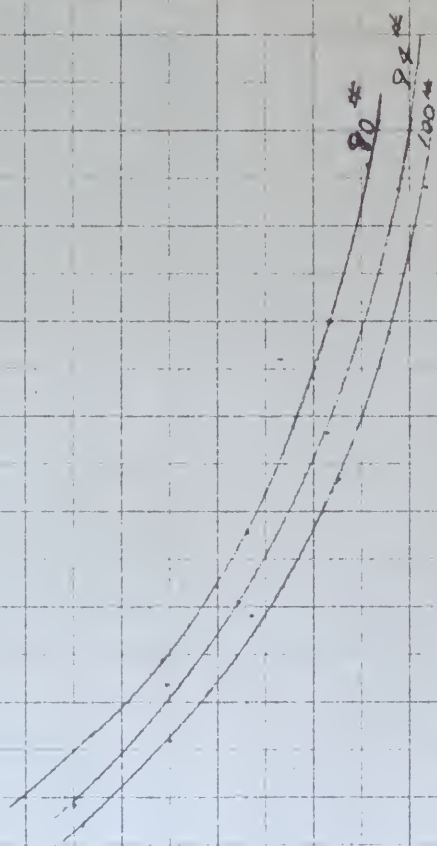


Fig-7-





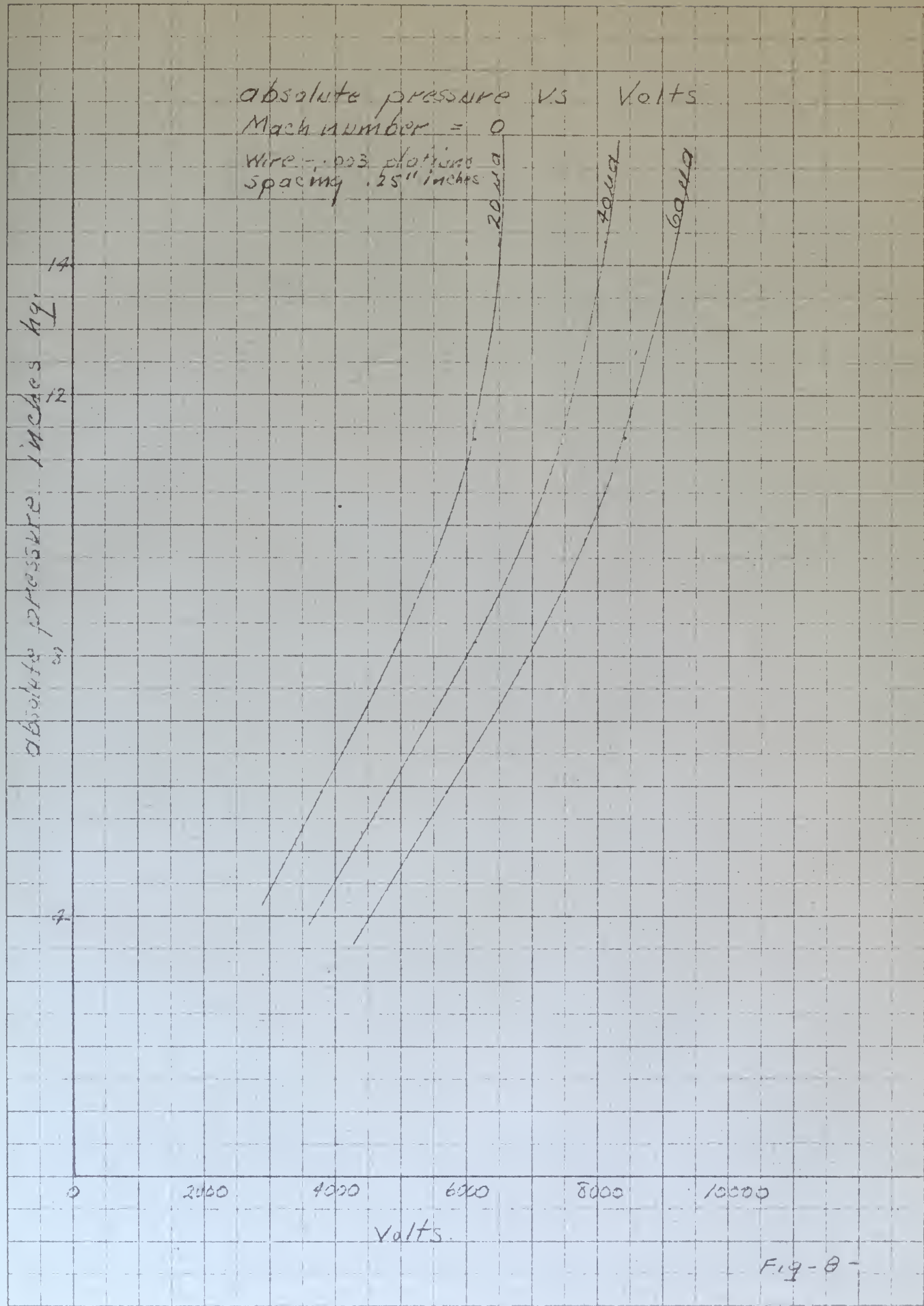


Fig-8-





# absolute pressure vs Volts

Mach number = 2.08

Wire = .003 platinum

Spacing = .25 inches

absolute pressure inches Hg

16

14

12

8

4

0

2000

4000

6000

8000

10000

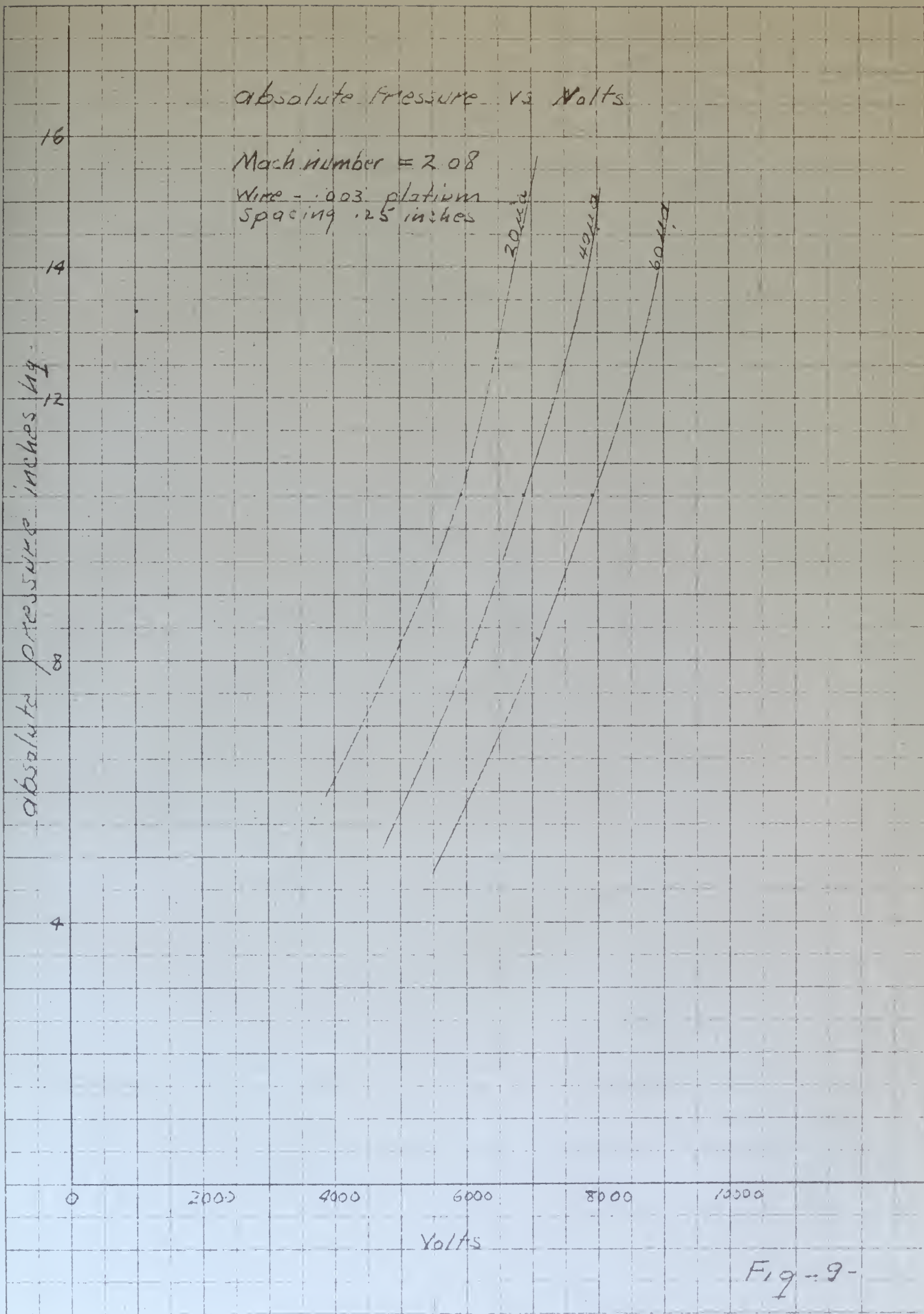
Volts

20 Volts

40 Volts

60 Volts

Fig-9-





absolute pressure vs Volts

Mach number = 2.44

Wire = .003 platinum

Spacing .25 inches

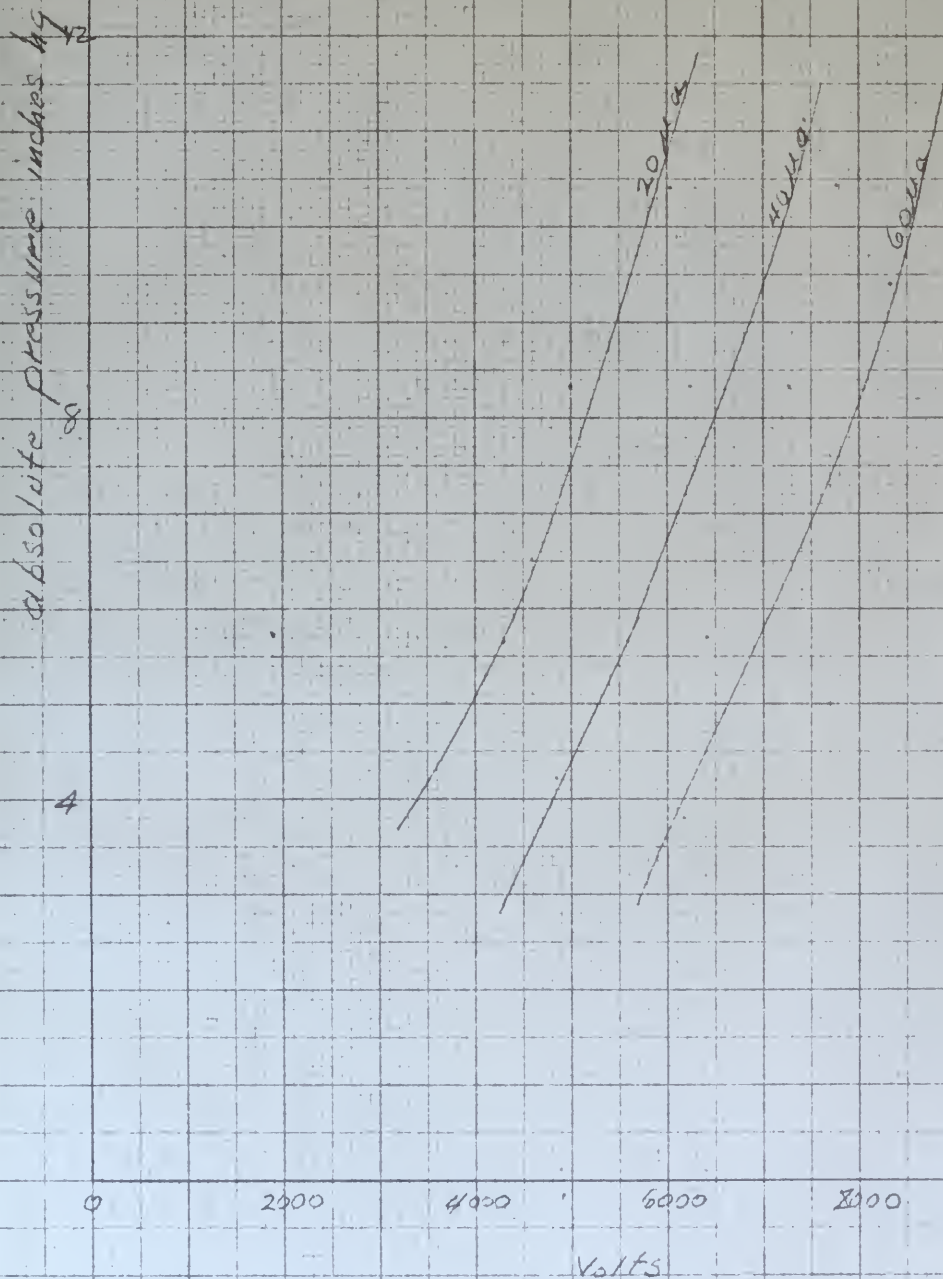


Fig-10-





Absolute Pressure vs Volts

Mach number 2.81

Wire .002 platinum

Spacing .25 inches

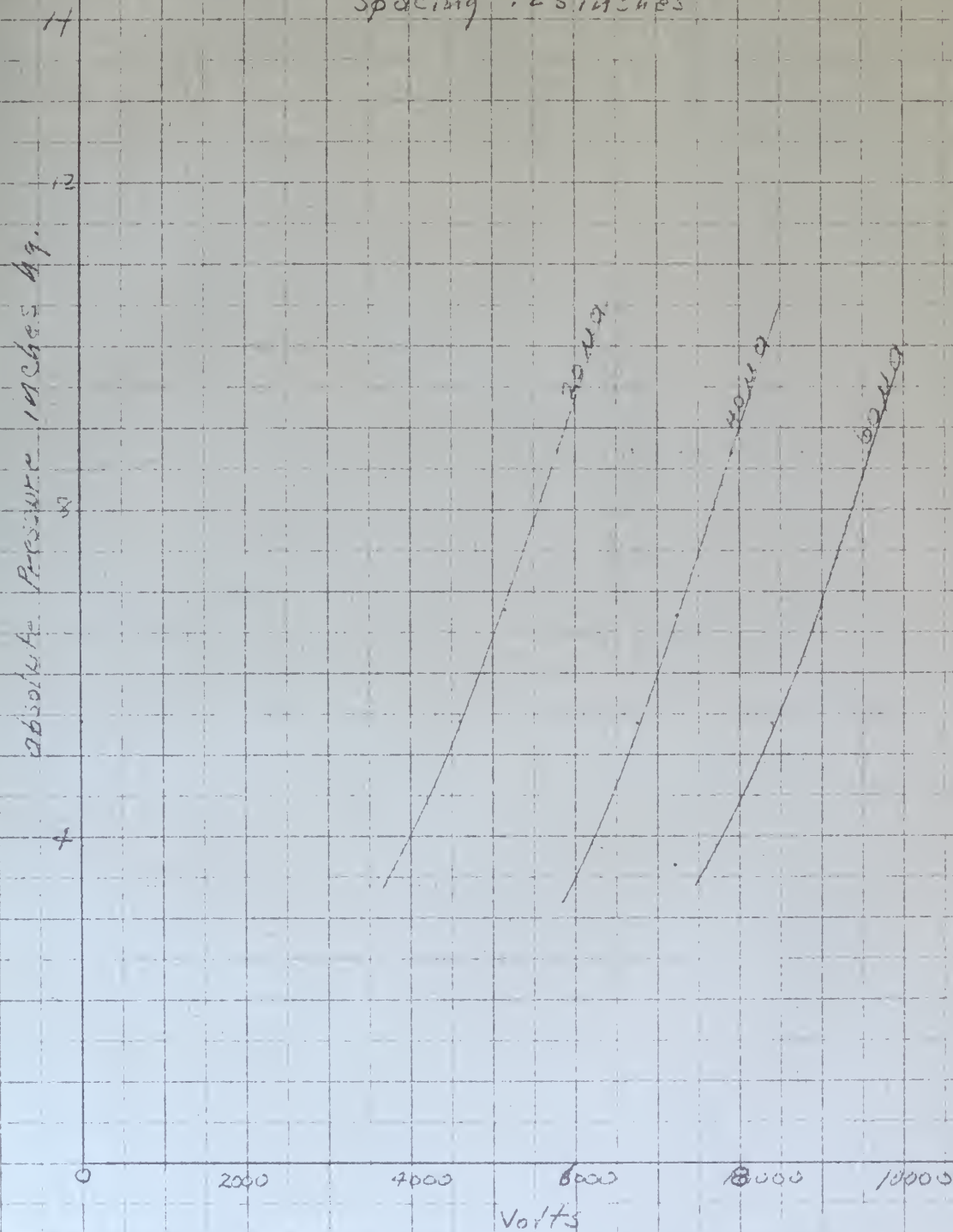


Fig-11-





absolute pressure vs Volts  
 Mesh number 3.1  
 Wire .003 platinum  
 Spacing .25 inches

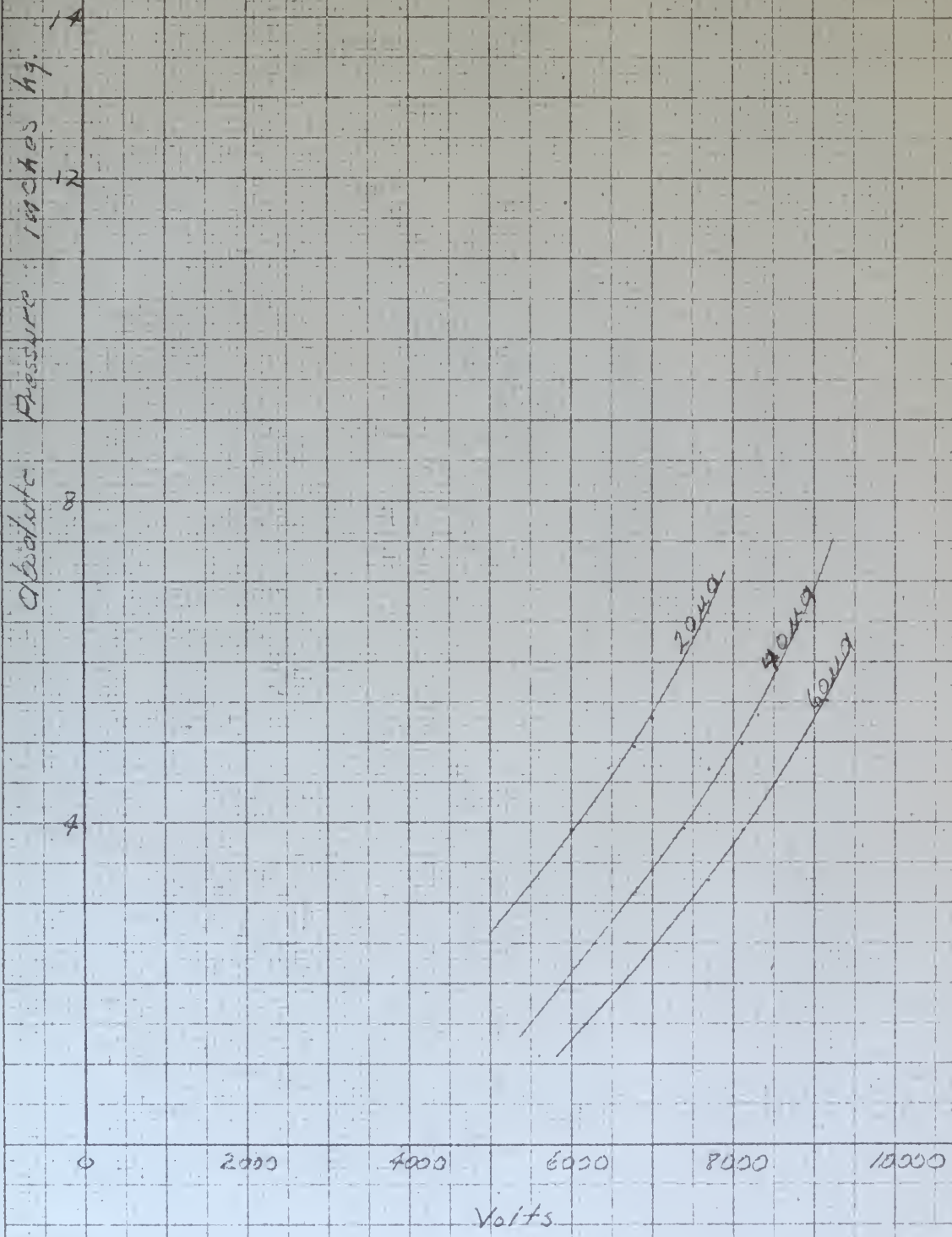


Fig-12-



Microamps vs. Volts at const. obs. Pressure  
absolute pressure = 5 inches hg.

Wire - .003 platinum  
Spacing - .25 inches

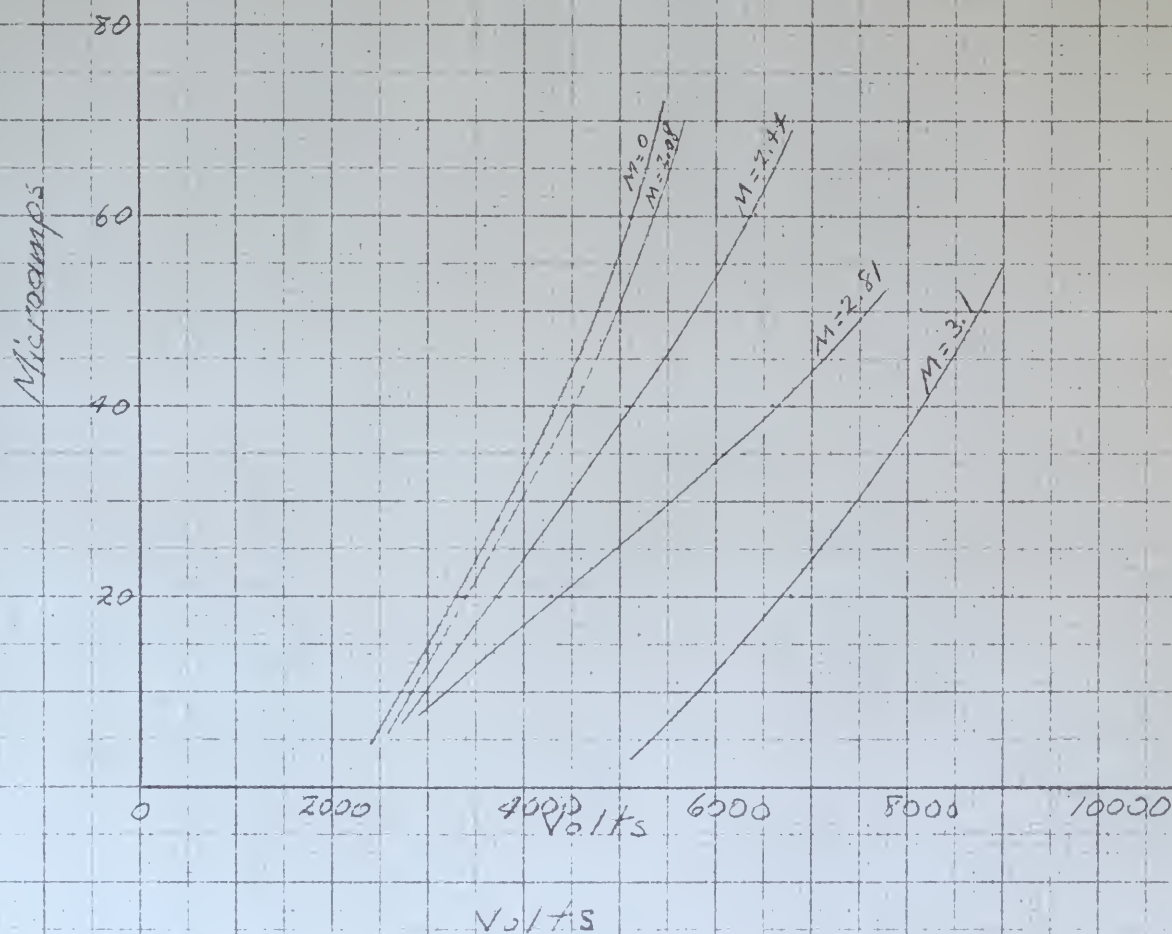


Fig-13-





Voltage vs Current for absolute pressures  
between 29.14 inches Hg and 4.46 inches Hg.

Mark number equal 0

Wire .003 platinum ; spacing .125 inches

Dry air

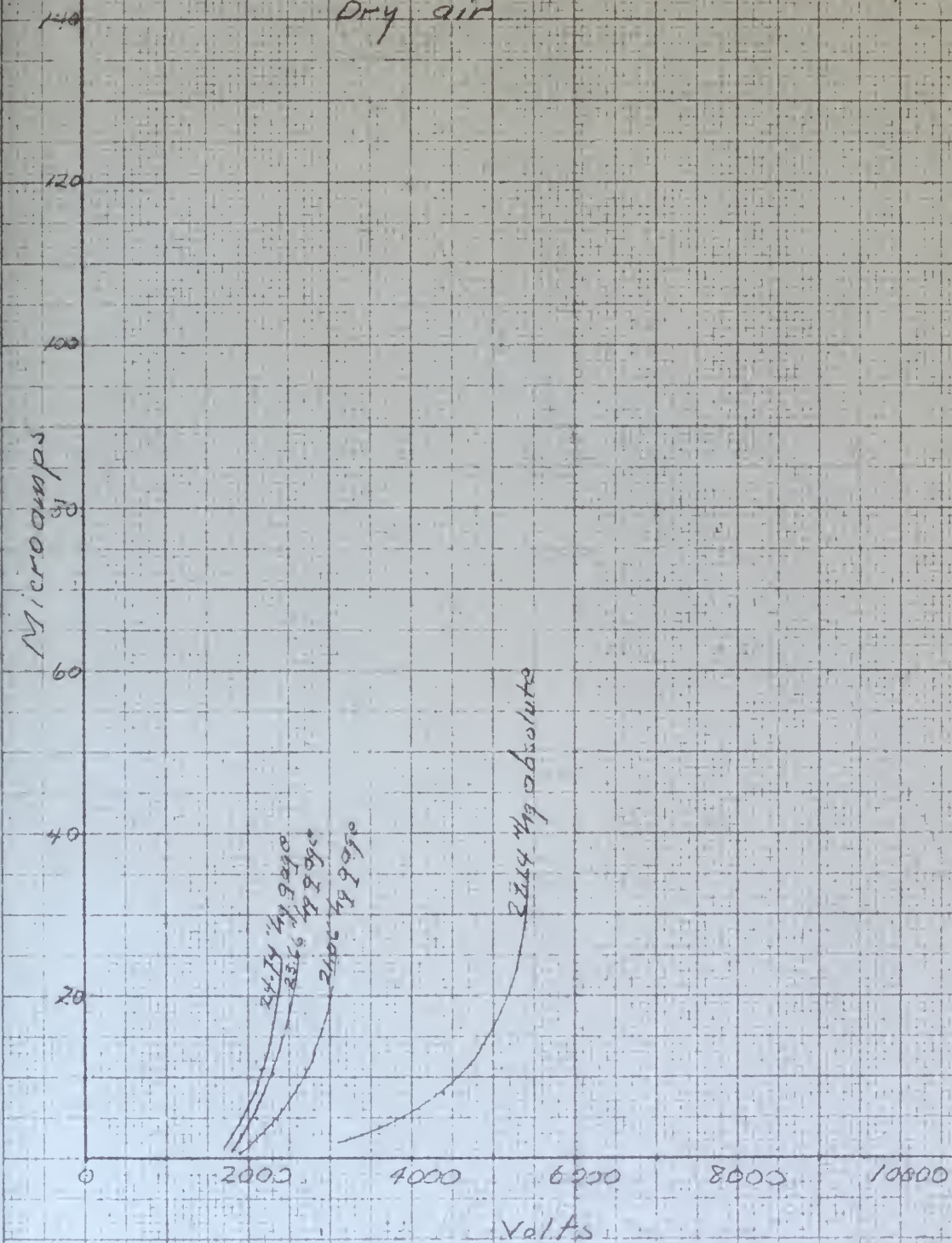


Fig - 1.4 -





## Microamps vs Volts

Wire .003 platinum spacing .125"

Position .6 inches in nozzle

Mach number 1.62

Stagnation pressure	21.9 #/in <sup>2</sup> abs	Static probe	4.94 #/in <sup>2</sup> abs
"	21.2 #/in <sup>2</sup> abs	"	4.88 #/in <sup>2</sup> abs
"	26.2 #/in <sup>2</sup> abs	"	6.51 #/in <sup>2</sup> abs

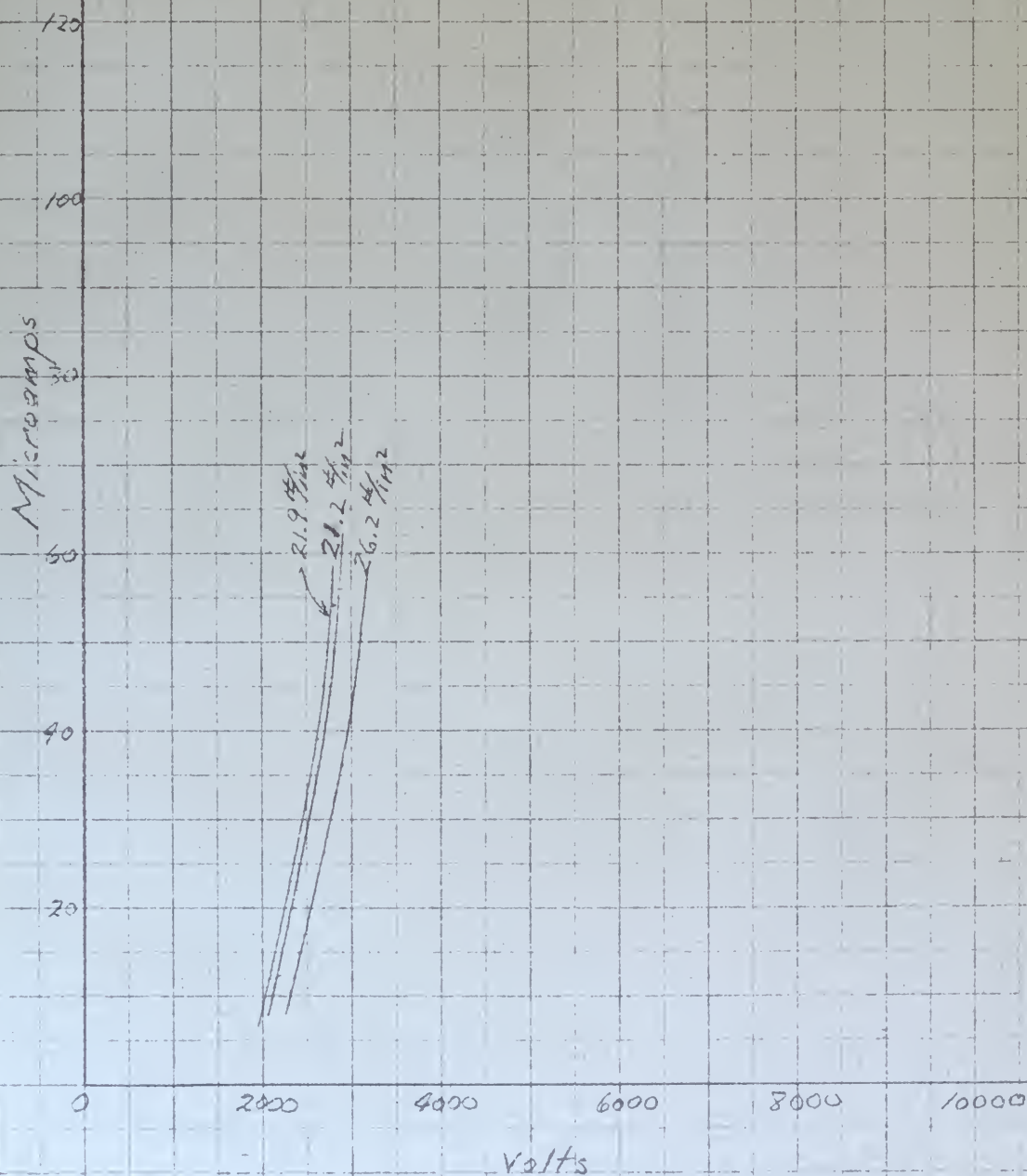


Fig-15-



# Microamps VS Volts

Wire .003 platinum  
 Spring .125"  
 Position in nozzle 1"  
 Mach number - 2.03

Stagnation pressure at 25  $\frac{\text{lb}}{\text{in}^2}$  gage; probe (static) 10.3  $\frac{\text{lb}}{\text{in}^2}$   
 " 30  $\frac{\text{lb}}{\text{in}^2}$  " 1.15  $\frac{\text{lb}}{\text{in}^2}$   
 " 40  $\frac{\text{lb}}{\text{in}^2}$  " 7.15  $\frac{\text{lb}}{\text{in}^2}$

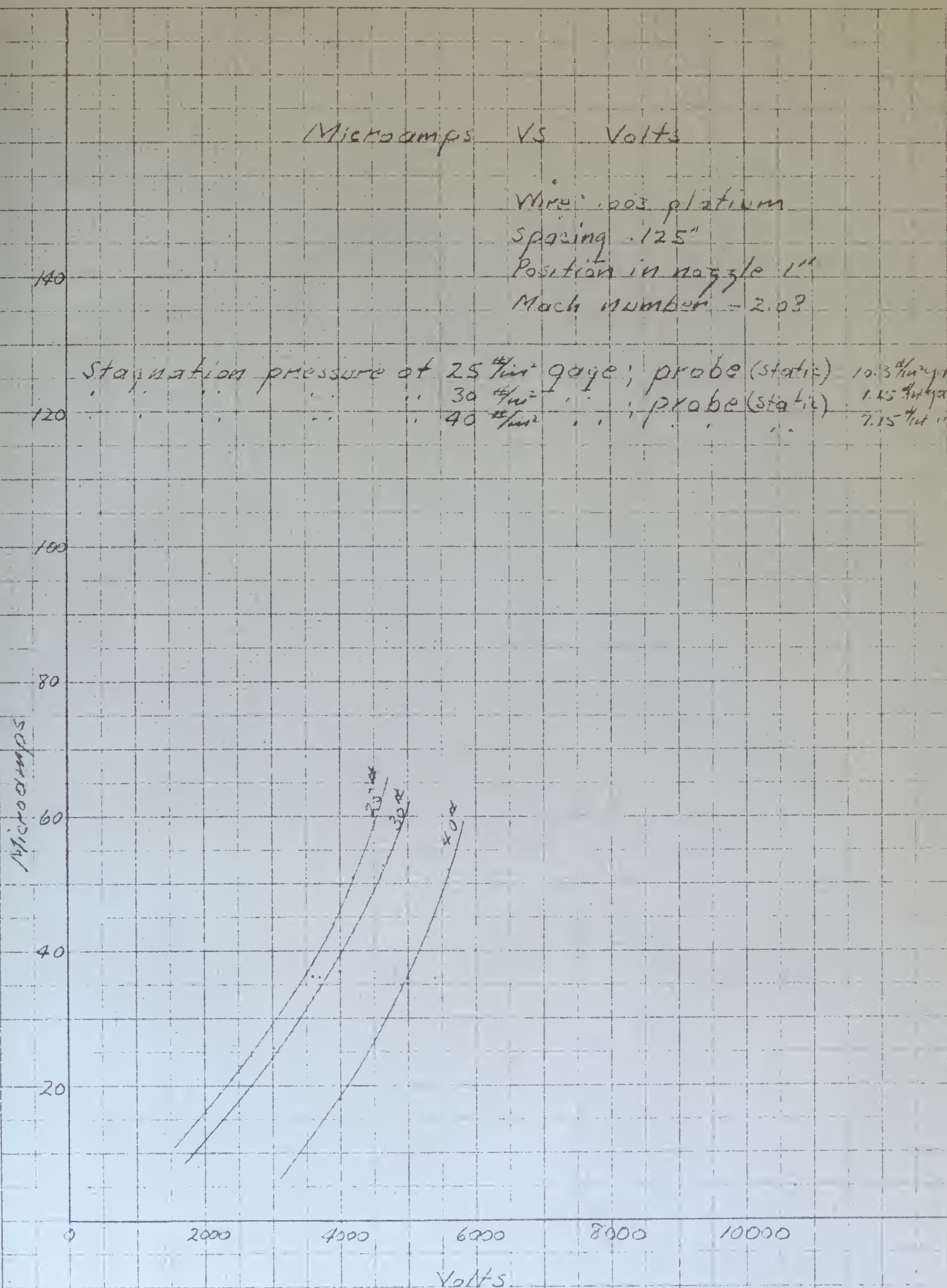


Fig-16-





# Microamps VS Volts

.003 wire platinum  
 .125" spacing  
 2" position in nozzle  
 Mach number 2.49

Stagnation pressure at 40  $\frac{lb}{in^2}$  gage static probe 11.5  $\frac{lb}{in^2}$  gage  
 50  $\frac{lb}{in^2}$  " " " " 10.2  $\frac{lb}{in^2}$  " "  
 60  $\frac{lb}{in^2}$  " " " " 9.2  $\frac{lb}{in^2}$  " "

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

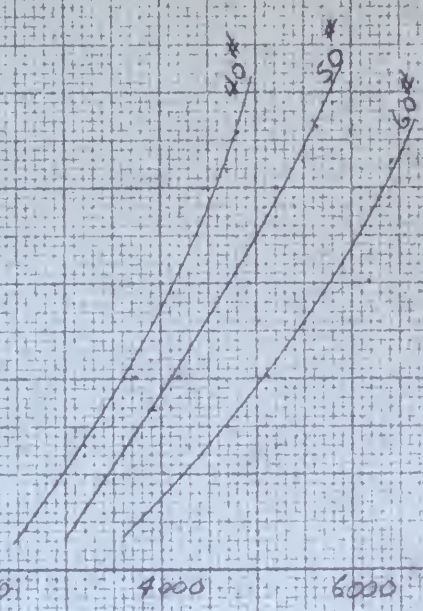


Fig-17-





Microamps VS Volts

Wica, 1003 platinum  
 scaling 12.5  
 Mach number 2.81  
 position in nozzle 3"

stagnation pressure of 70  $\frac{\text{ft}}{\text{min}}$  gage static probe 11.7  $\frac{\text{ft}}{\text{min}}$  gage  
 80  $\frac{\text{ft}}{\text{min}}$  " " 11.0  $\frac{\text{ft}}{\text{min}}$   
 90  $\frac{\text{ft}}{\text{min}}$  " " 10.2  $\frac{\text{ft}}{\text{min}}$

Microamps

70\*

80\*

90\*

140

20

0

2000

4000

6000

8000

10000

Volts

Fig-1B-





# Microamps Vs Volts

Wire .003 platinum  
Spacing .125  
Noch number - 3.1  
position in 1133/10 4"

Stagnation pressure of 90  $\frac{\text{lb}}{\text{in}^2}$  static probe 12.4  $\frac{\text{lb}}{\text{in}^2}$   
" " " 94  $\frac{\text{lb}}{\text{in}^2}$  " " 12.1  $\frac{\text{lb}}{\text{in}^2}$   
" " " 100  $\frac{\text{lb}}{\text{in}^2}$  " " 11.57  $\frac{\text{lb}}{\text{in}^2}$

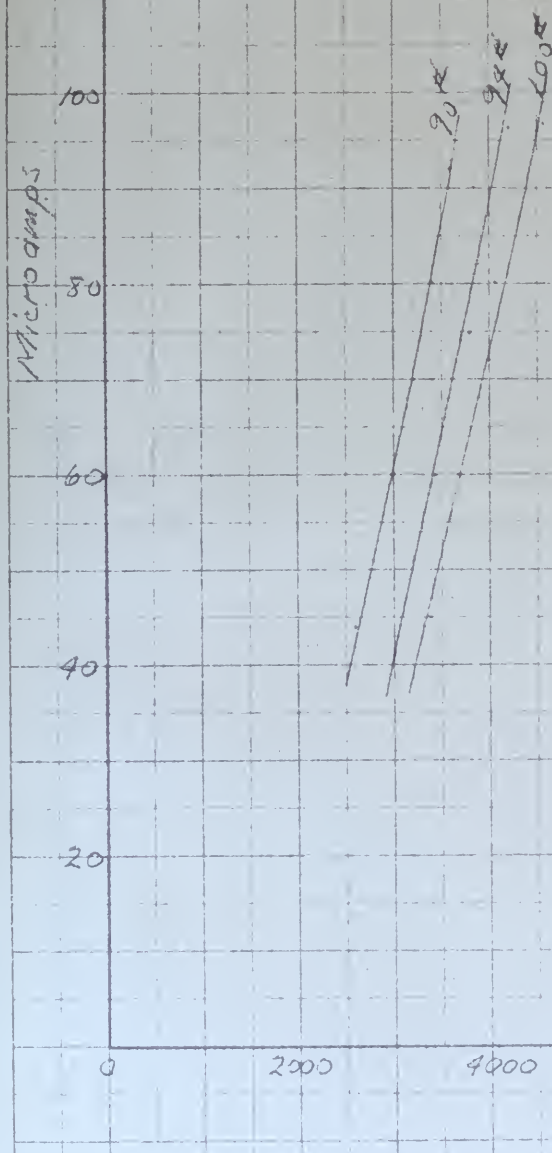


Fig-19-





absolute pressure vs Volts

Mach number = 2.08

Spacing = 125 inches

Wire = 003 platinum

absolute pressure inches hg

1000g

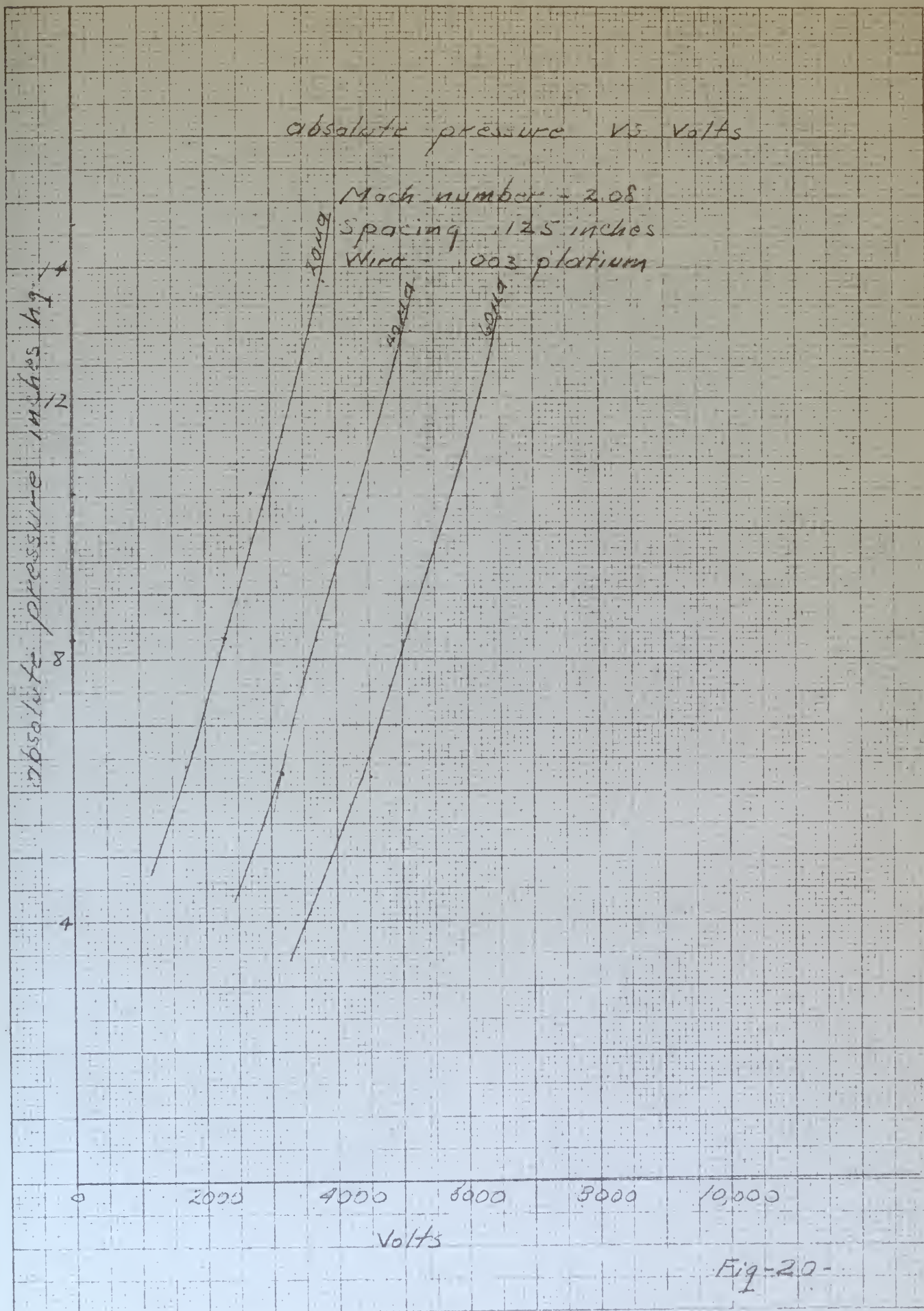
4000g

6000g

0 2000 4000 6000 8000 10,000

Volts

Fig-20-







absolute pressure vs Volts

Mach number 2.44

Spacing .125 inches

Wire .003 platinum

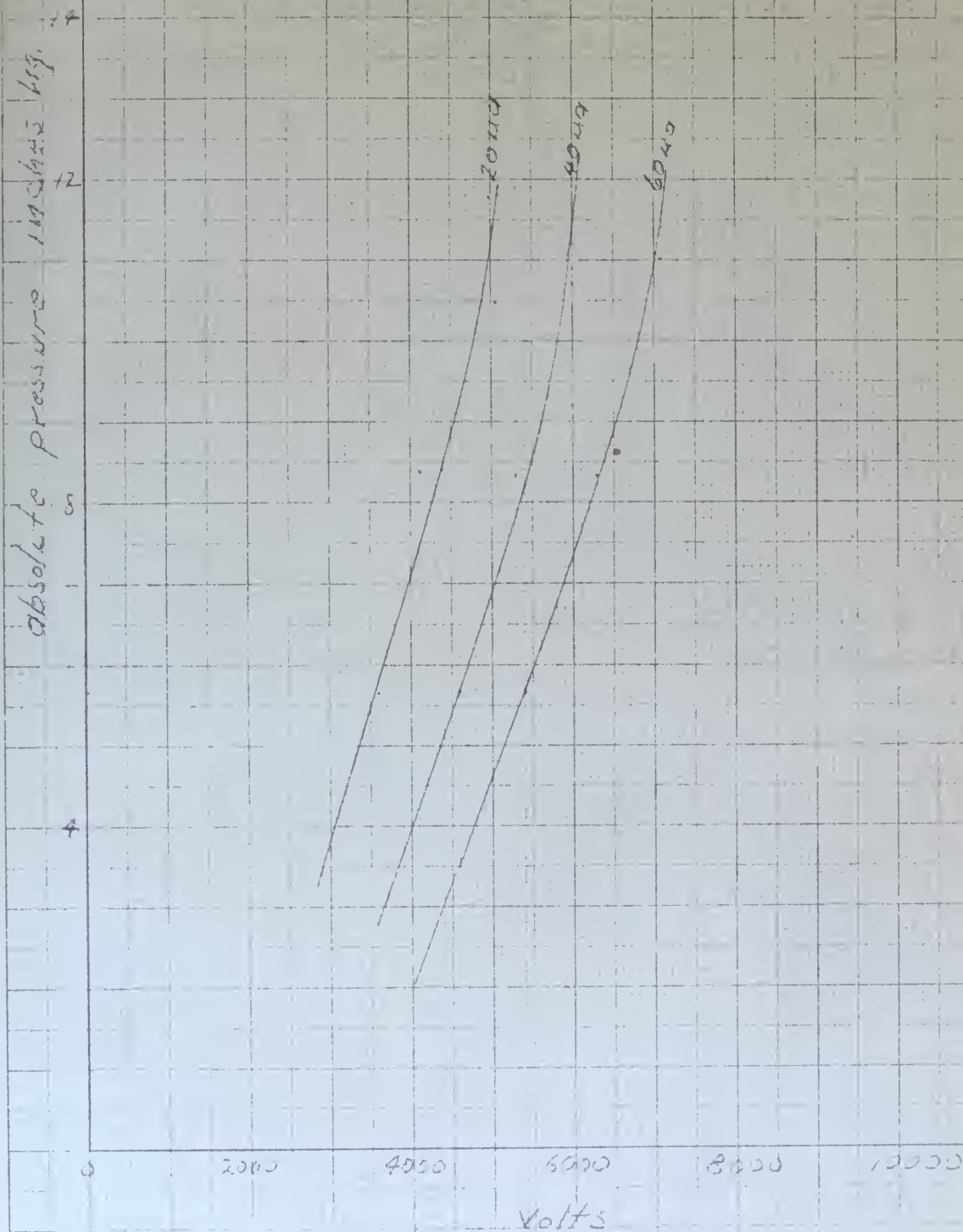


Fig-21-



absolute pressure vs. Volt

Mach number 2.81

Spacing .125 inches

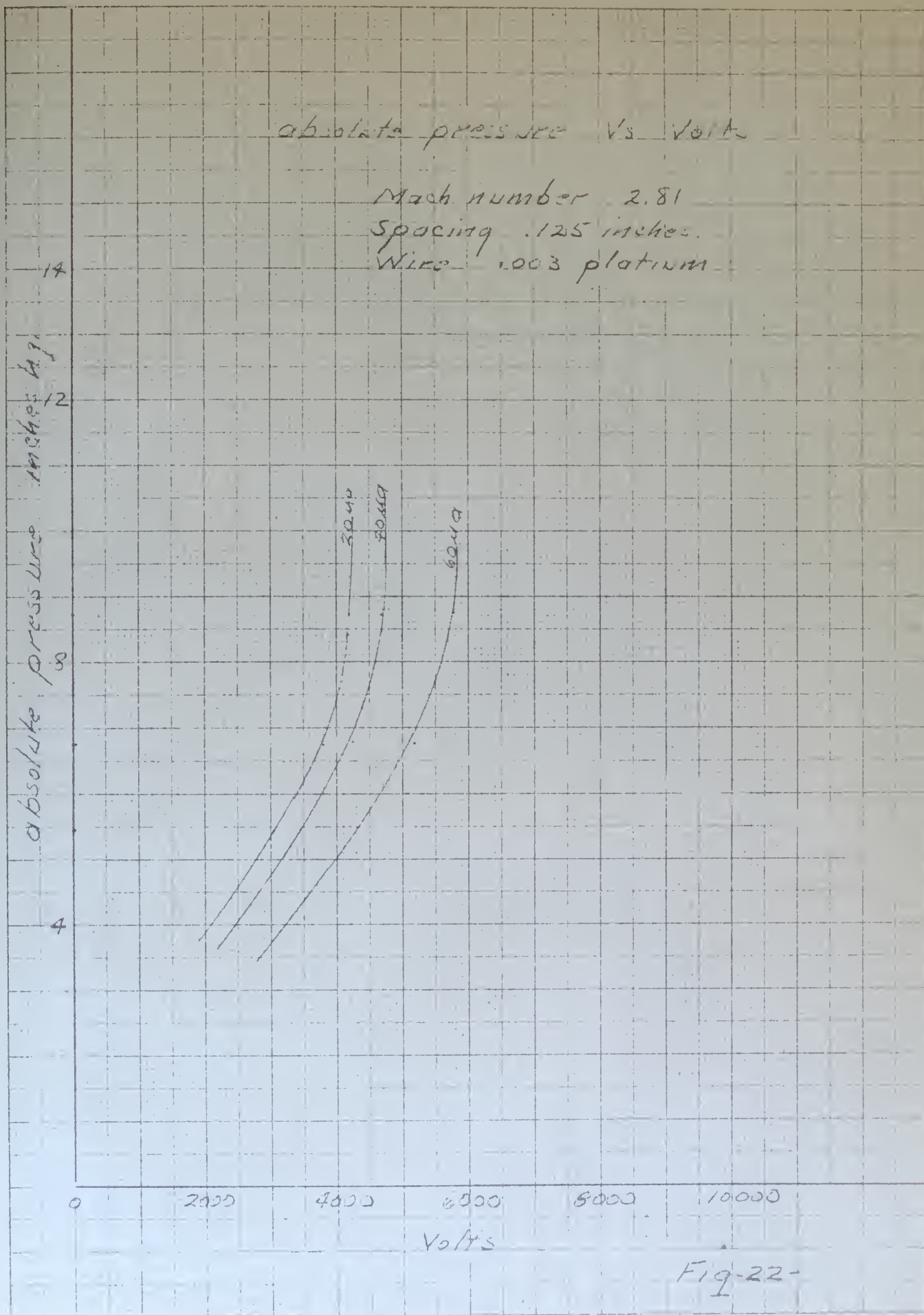
Wire .003 platinum

absolute pressure inches Hg

0 2000 4000 6000 8000 10000  
Volts

5000  
4000  
3000

Fig-22-







absolute pressure vs Volts

Mach number 3.1

Spacing .125 inches

Wire .003 platinum

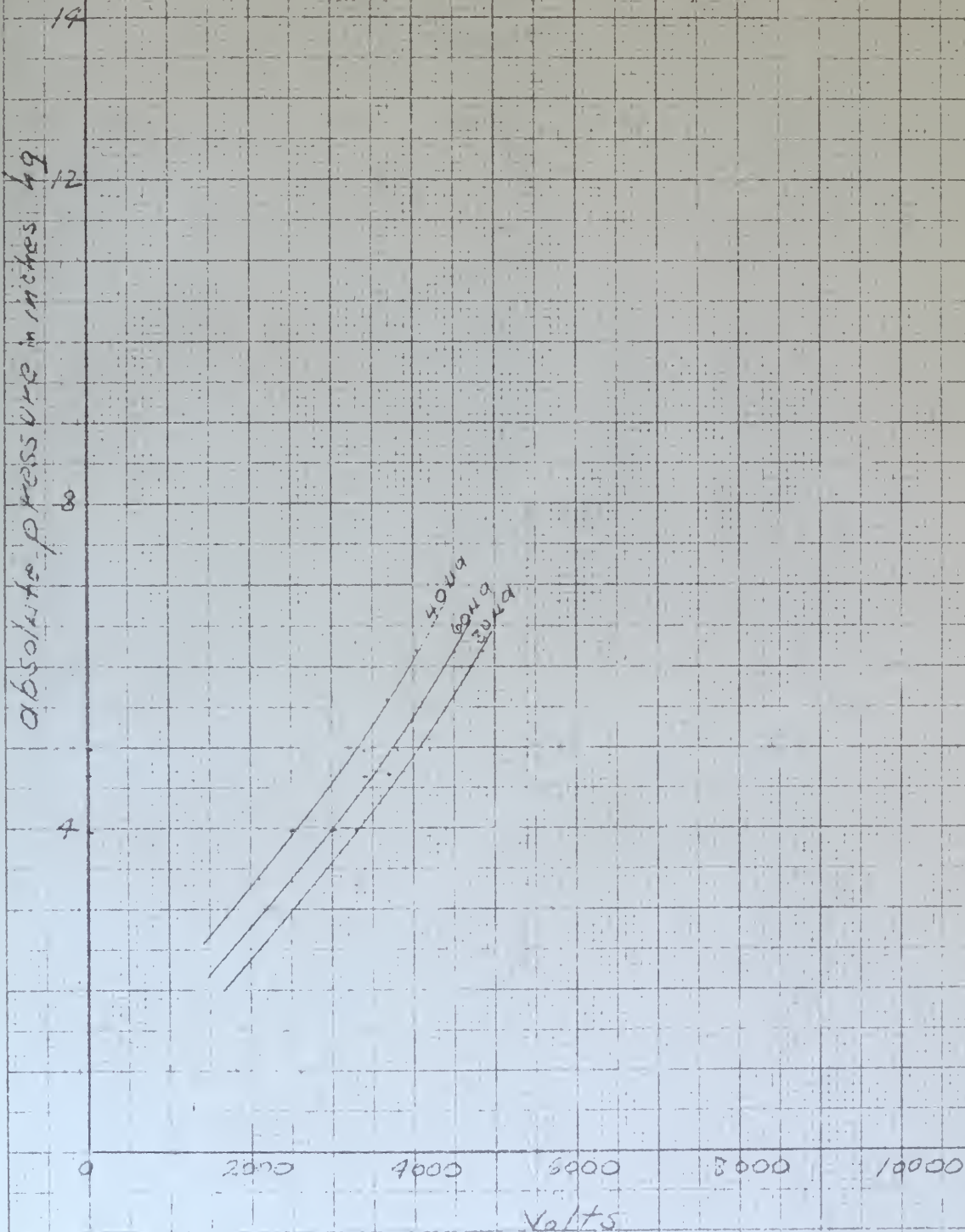


Fig-23-





Microamps vs Volts at const. abs. Pressure  
absolute pressure = 5 inches hg.

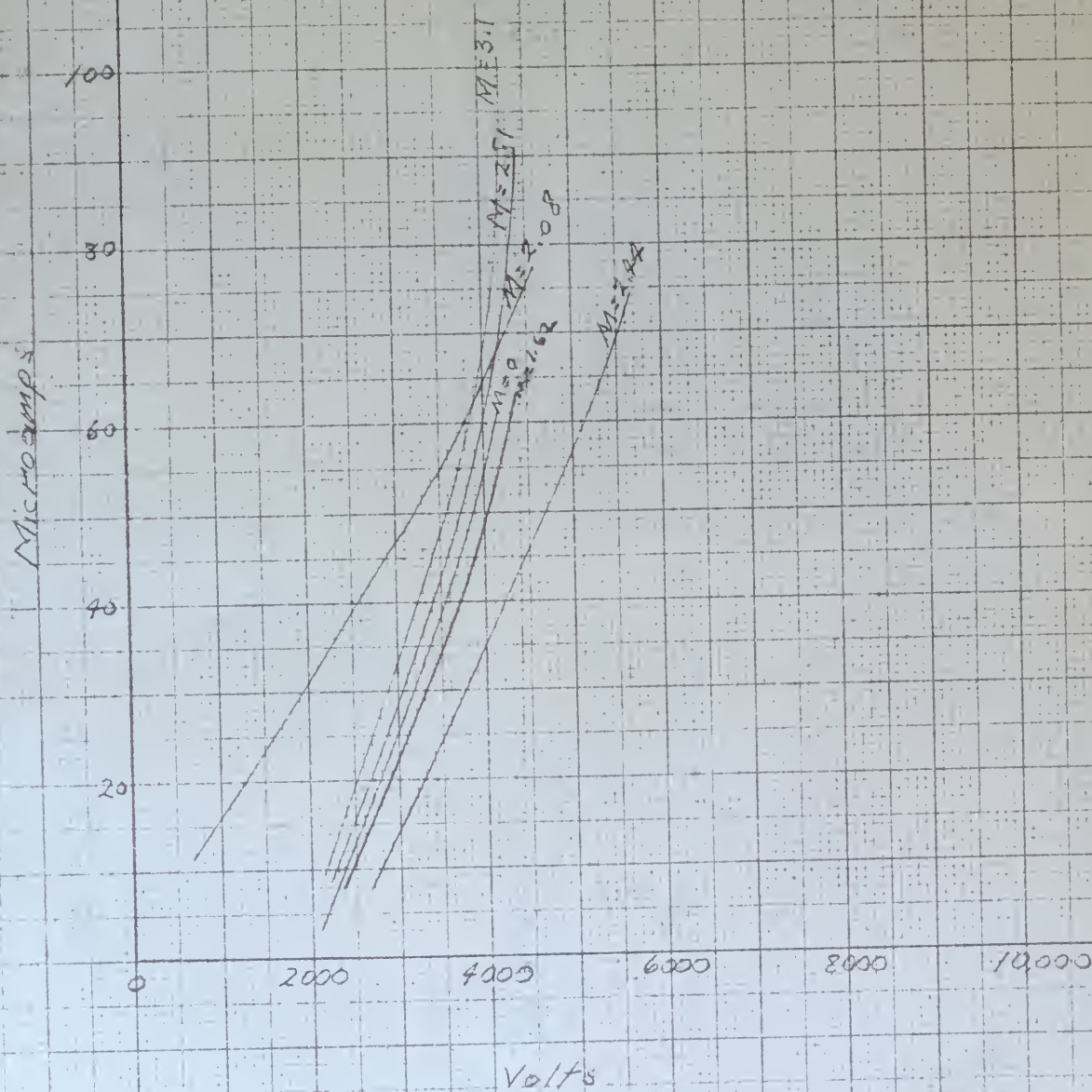
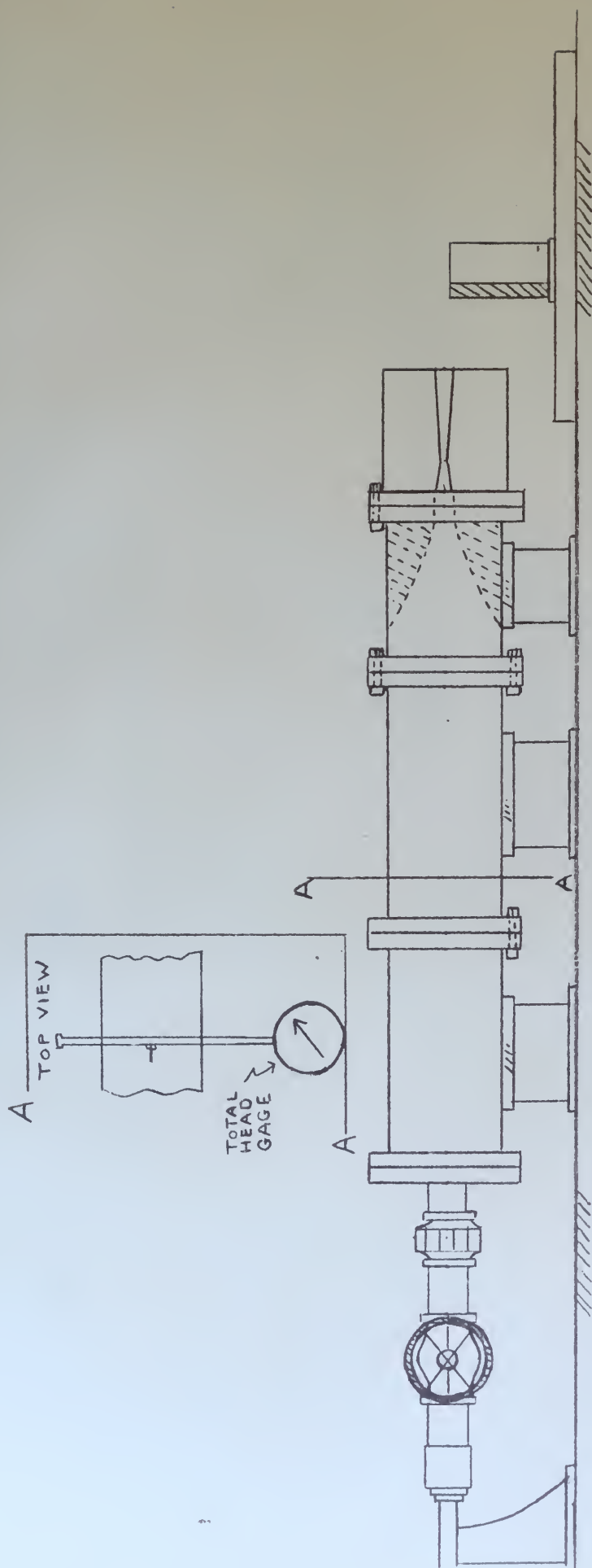


Fig-24-





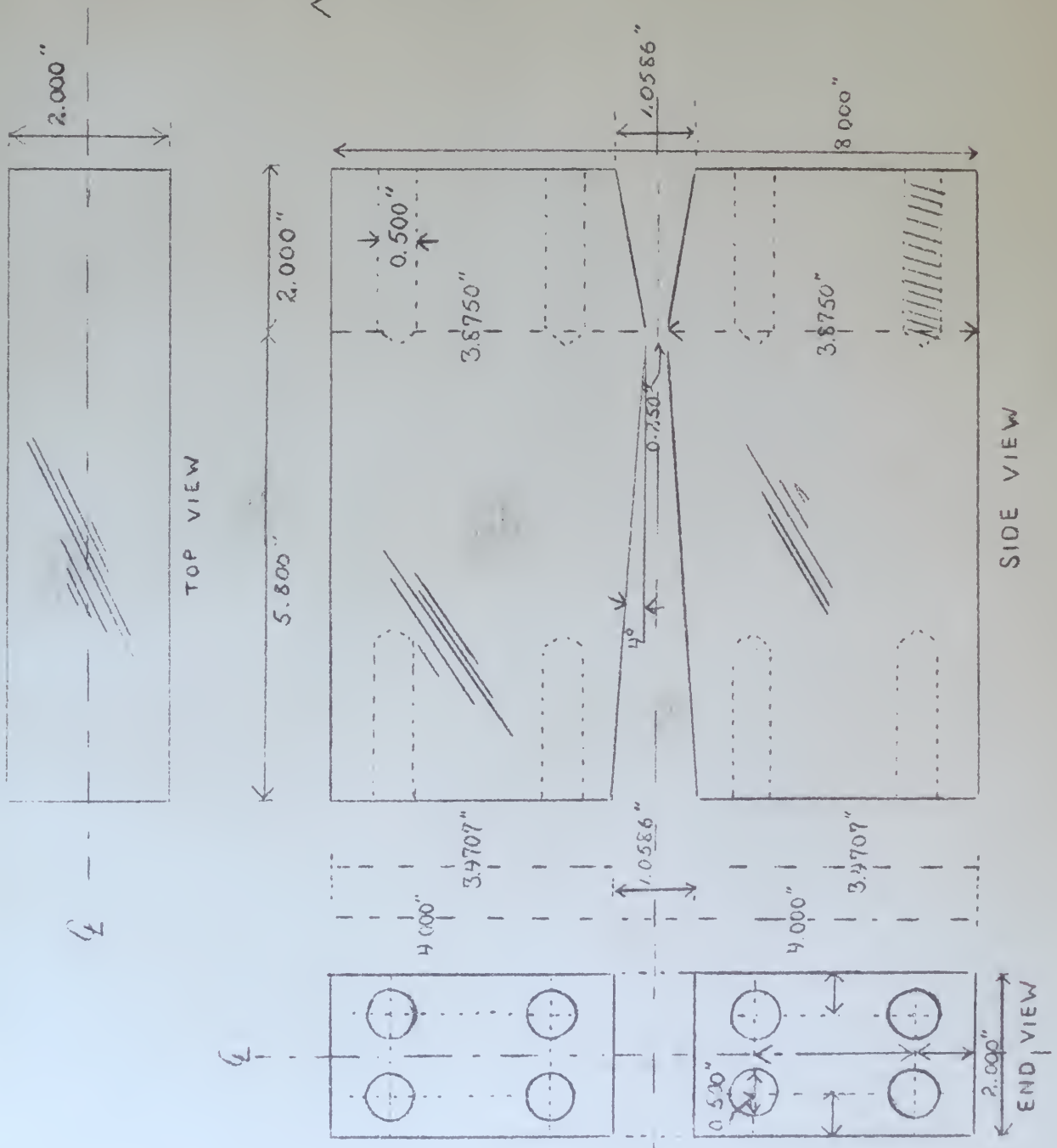
SCALE  $\frac{1}{10}'' = 1''$

SIDE VIEW  
WIND TUNNEL



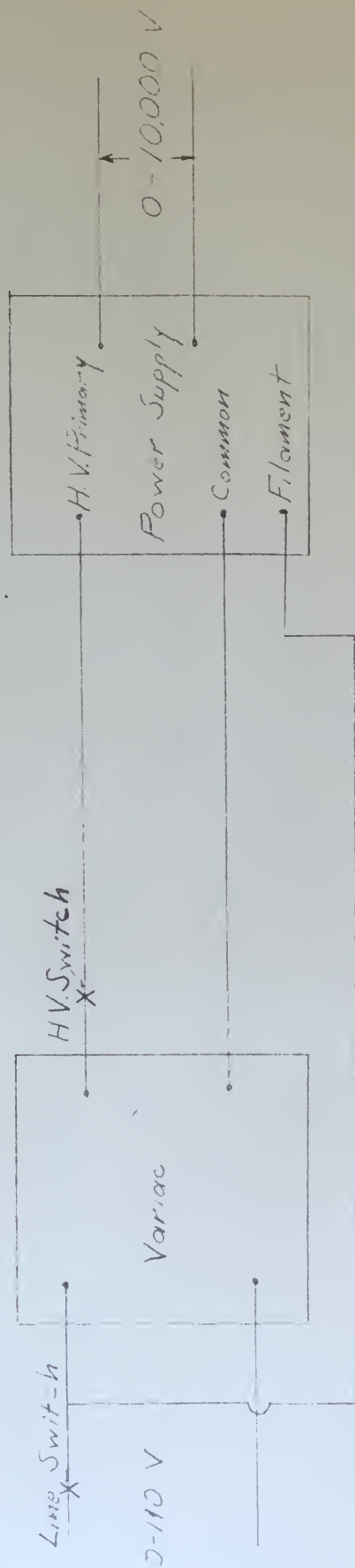


# NOZZLE BLOCK DESIGN



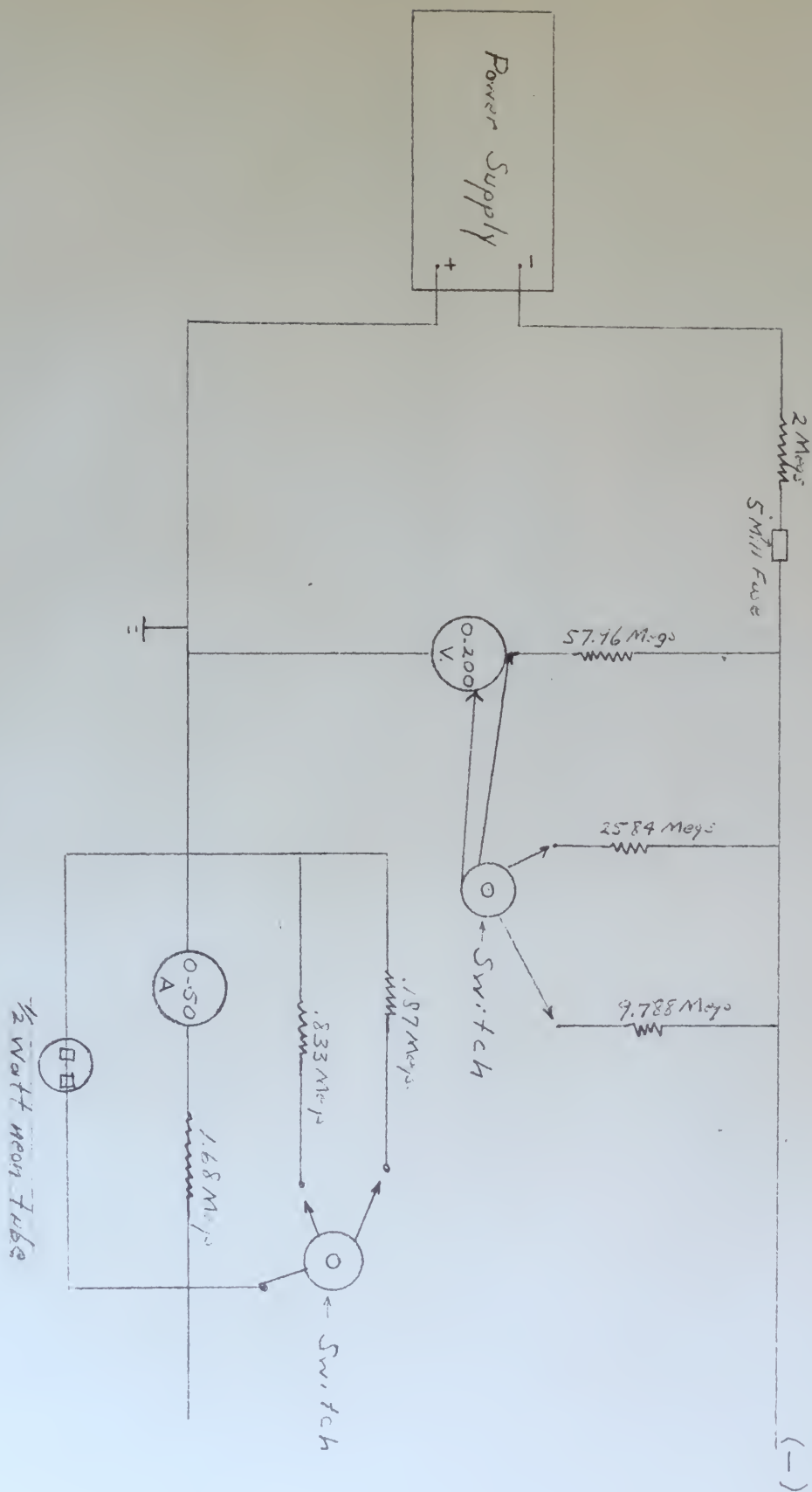






Power Supply

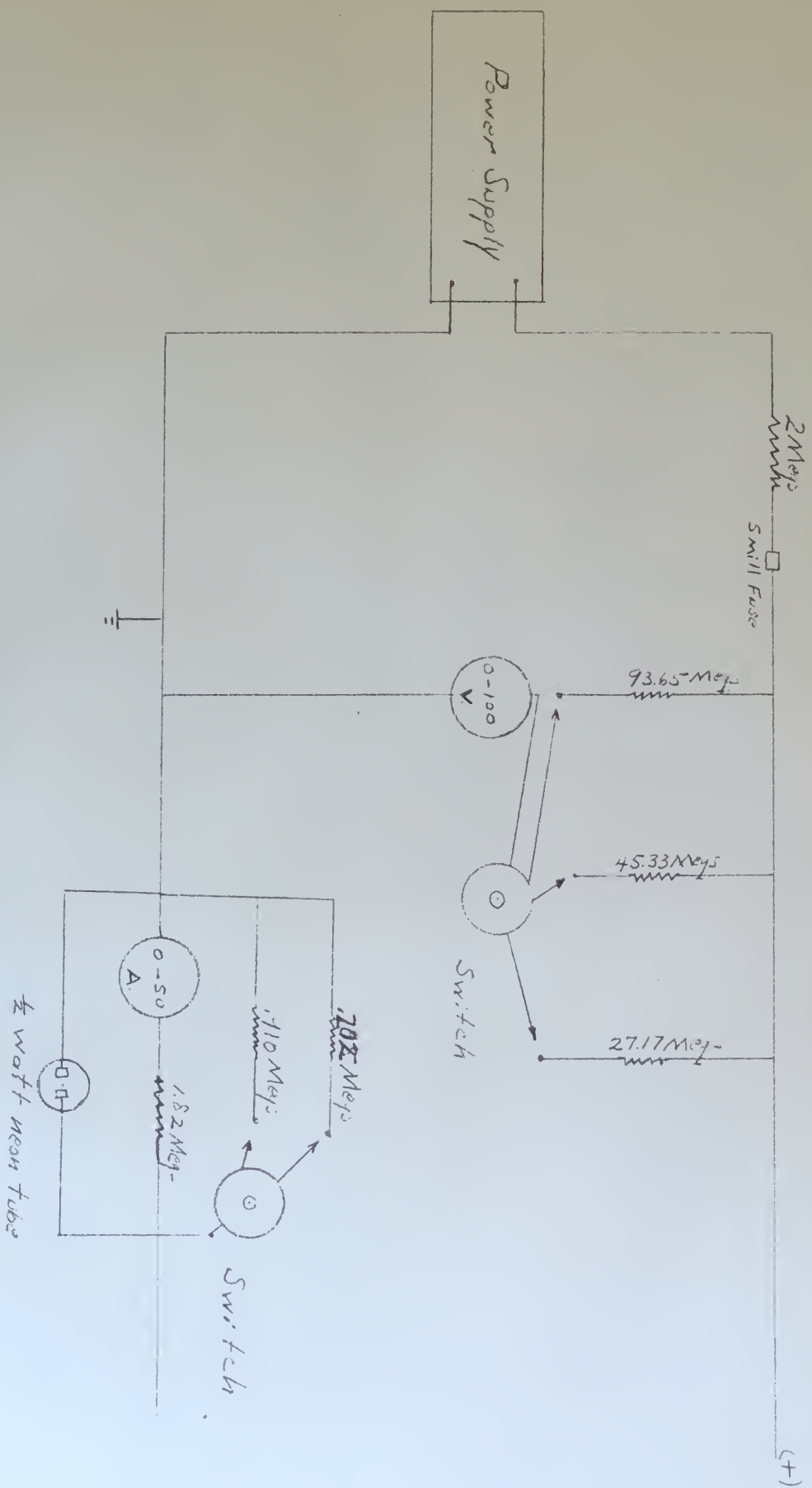




Circuit # 1





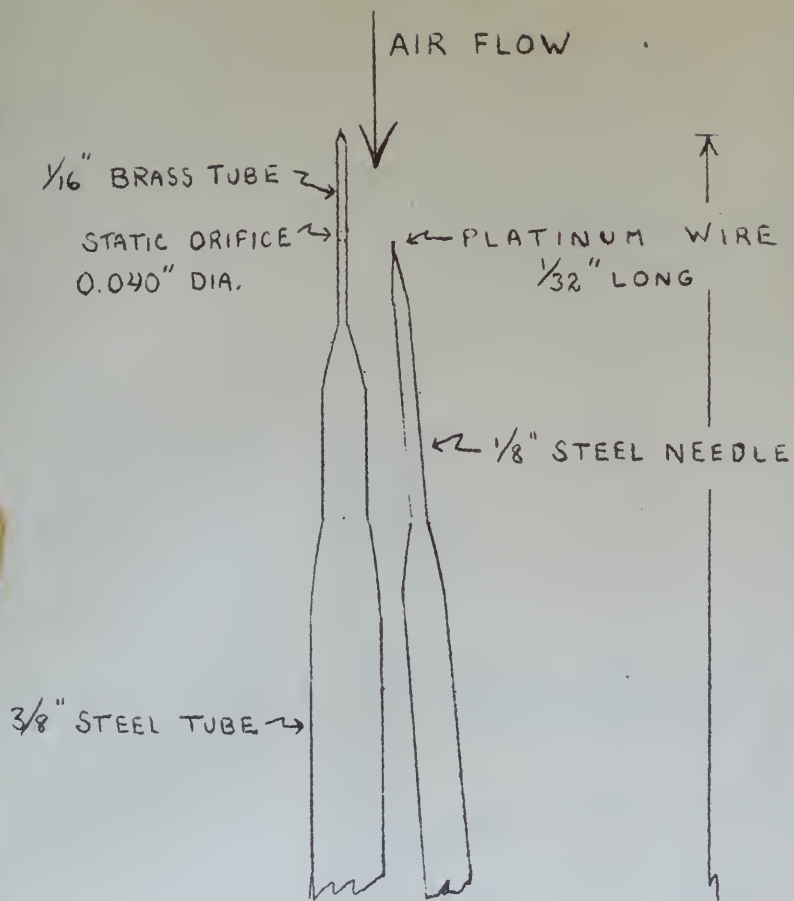


Circuit

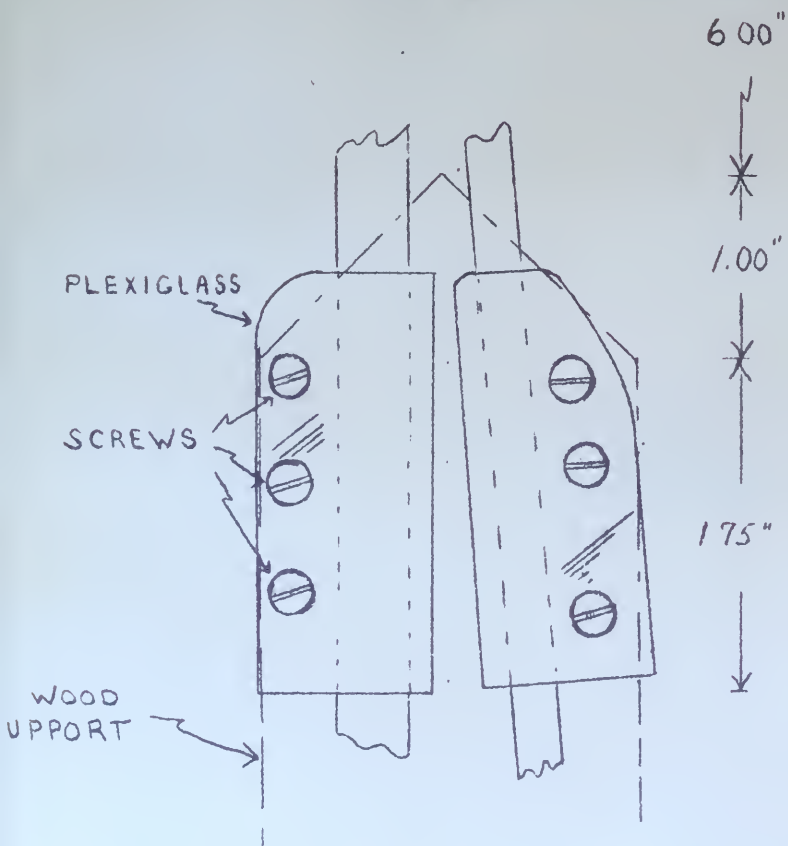
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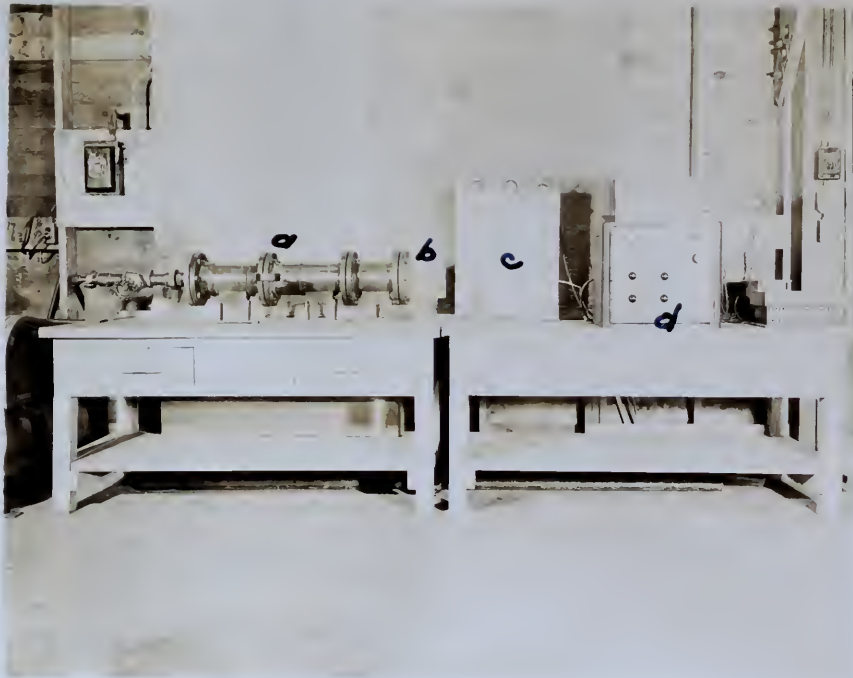


ARRANGEMENT of  
the PROBES





## WIND TUNNEL &amp; ELECTRONIC EQUIPMENT



- a - Stagnation Chamber
- b - Nozzle
- c - Manometer Board
- d - Electronic Equipment

Fig. 31



THE JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION



1 - American Medical Association  
 2 - Board of Directors  
 3 - American Medical Association  
 4 - American Medical Association

## NOZZLE BLOCKS, PROBES &amp; VACUUM JAR

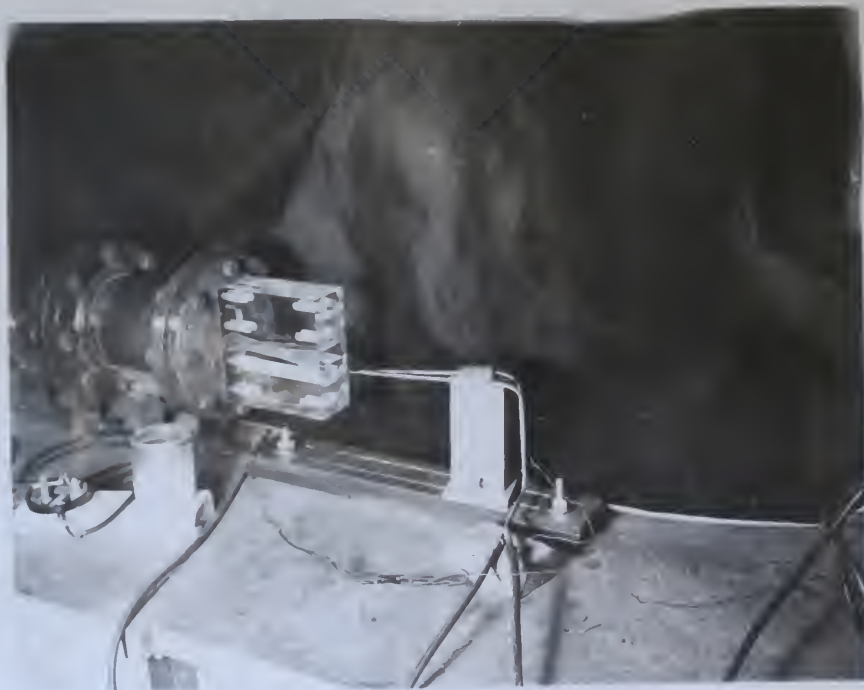
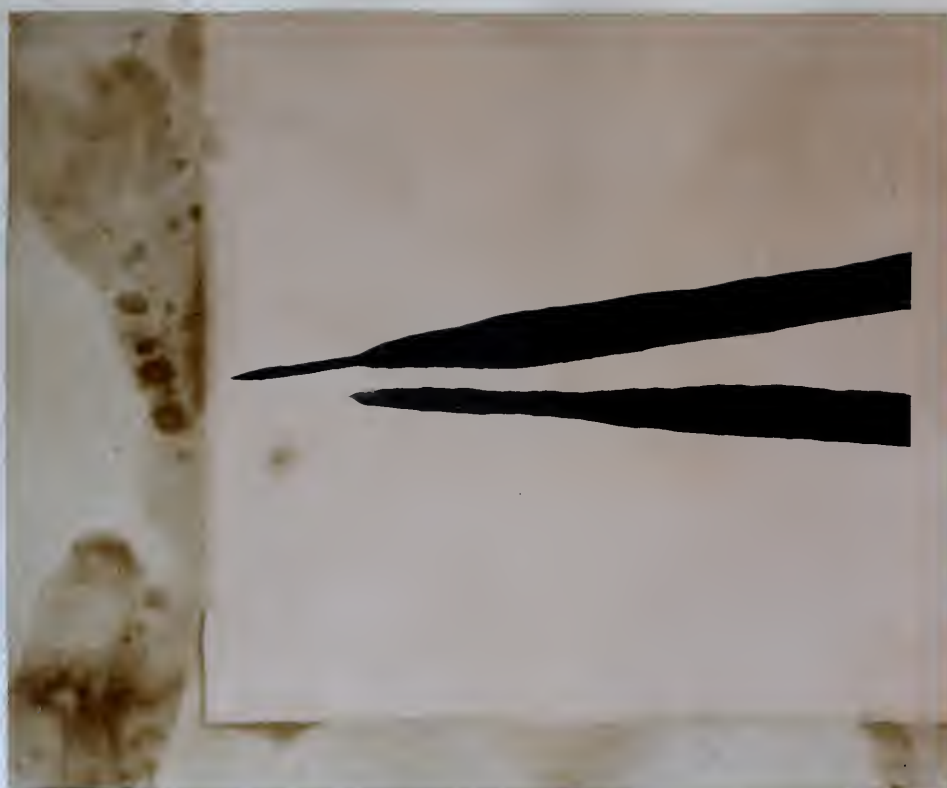


Fig. 32

THE HISTORY OF THE





Static Probe

Platinum Wire  
Probe

PROBES, SPARK PHOTOGRAPH

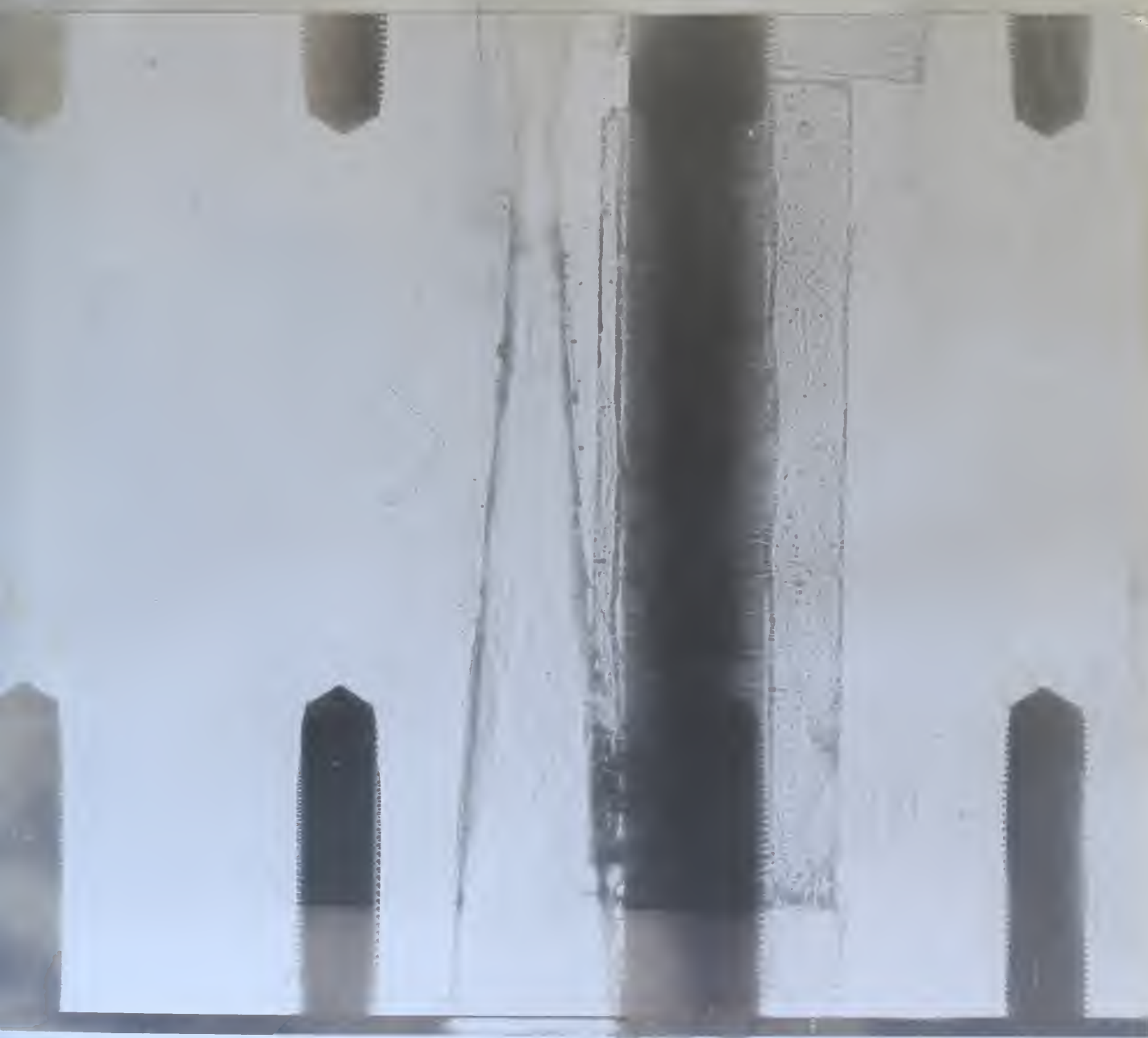


Specimen No. 100

Specimen No. 101



Specimen No. 102







$M = 2.81$ ; Stagnation Pressure 90#/in.<sup>2</sup> gage







Prober Inserted  
 $M = 2.81$  Stagnation Pressure 90#/in.<sup>2</sup> gage

Fig. 36







## DATE DUE

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